MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

JANUARY•FEBRUARY 1999

100th ANNIVERSARY SINCE 1899

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A LETTER FROM OUR PUBLISHER

"INNOVATION IS INVENTION APPLIED." THOSE WORDS WERE spoken on April 23, 1998, at *Technology Review*'s relaunch event here at MIT by Dr. John Seely Brown, director of Xerox's famed Palo Alto Research Center (PARC). Those four words are a remarkably accurate description of the transformation of *Technology Review* from 1899 to the present. The issue before you marks the present and looks to the future. It also begins the celebration of our 100th year of publication.

When John Seely Brown joined us last April, along with other distinguished guests to introduce the new *Technology Review*, we were pleased to present a bold new look and editorial focus. The May/June 1998 issue presented that day was the first evidence of a process that began two years ago when we began to reexamine our mission, our benefit to our owners at MIT, our position in a changing and competitive marketplace, and our value to you—our readers. With this plan we committed ourselves to improve the quality of our writing, expand our subscriber base, be more available on newsstands, increase our advertising revenue and enhance our Web presence.

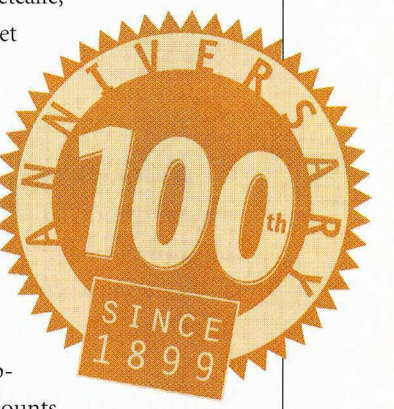
We were fortunate to have John Benditt join us in September 1997 as our editor in chief to complete this process. John brought a new editorial focus that is unique in the world of magazine publishing. He articulated and developed the editorial platform that would result in *Technology Review* becoming the only magazine that focuses on the process of technological innovation. The response has been overwhelmingly positive to the new editorial focus and look of *TR*.

Let me give you some evidence of the reaction to the new magazine.

- Our circulation has doubled—from 92,000 to more than 180,000.
- Our newsstand sales have quadrupled.
- Advertising pages and revenue have tripled.

This growth would not have been possible without the remarkable contribution of many people here at MIT, but most notably a dedicated board of directors. They are listed on page 8 on our masthead and posted on our Web site—www.techreview.com—with full biographical profiles. Please take a moment to review their backgrounds, and you will see why we have received such sound advice.

In September 1997, the *Technology Review* board made a commitment to provide the necessary capital to implement our plan with a fund-raising drive led by Bob Metcalfe, technology pundit, inventor of Ethernet and founder of 3Com. Bob is our first Millennial Patron (at a level of $250,000 or more). He is joined by Steve Kirsch, founder of Infoseek, who is a Centennial Patron ($100,000 or more). Other Patrons ($25,000 or more) such as DuWayne Peterson have also contributed. Their personal financial support is remarkable not only for the amounts given, but for the confidence they place in the importance of our mission. We honor them as our patrons with a deep sense of appreciation.

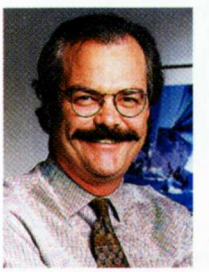


There is a natural inclination when celebrating a special anniversary to look back. We could easily chronicle the past 100 years of technology as covered in our pages. Yet we would rather look to the future. In our 1999 year-end issue, *Technology Review* will name the TR 100: The Top 100 Young Innovators. These 100 innovators will be those who have the greatest potential to make a path-breaking technological innovation in the decades to come. We will be choosing this group throughout the year, which will culminate with a gala celebration here at MIT at the close of 1999.

There is a natural inclination when celebrating a special anniversary to look back. We could easily chronicle the past 100 years of technology as covered in our pages. Yet we would rather look to the future.

To determine this elite list of 100 young innovators, we will be soliciting nominations from you, our readers, as well as from others. In upcoming issues we will give you more details on the criteria that will be used for the nominees and the nominating committee who will recommend them to our editors. They are people with a great deal of experience in determining and evaluating potential.

As *Technology Review* begins its centennial year, we have much to look forward to, particularly the TR 100. We hope you will join us as we celebrate the future—as well as our diverse and distinguished past.



R. Bruce Journ

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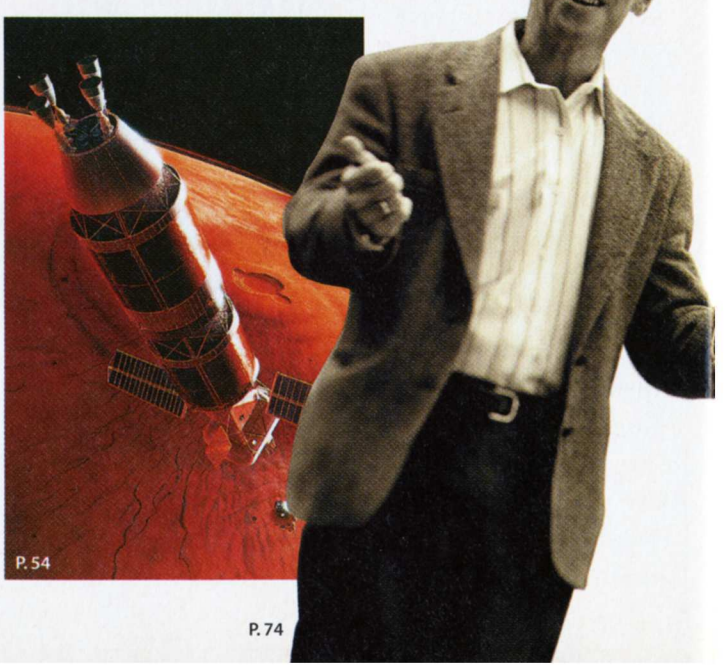
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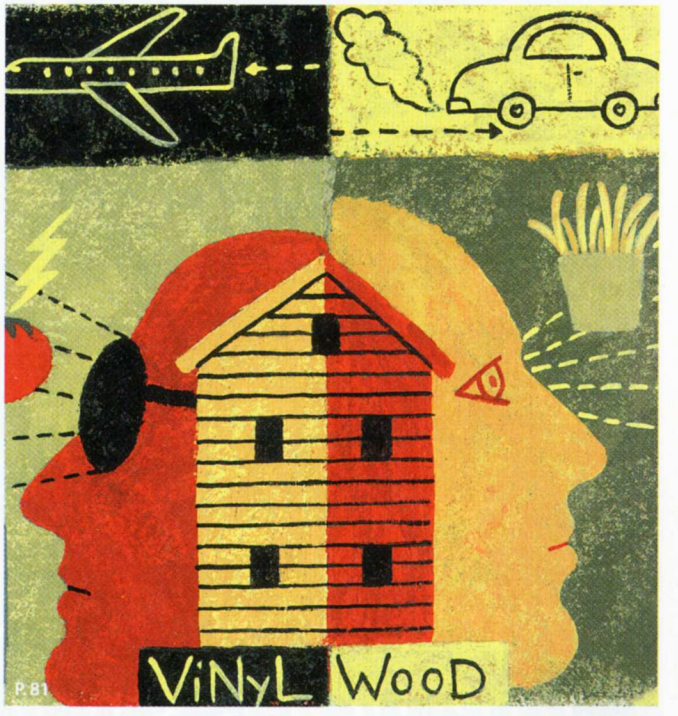
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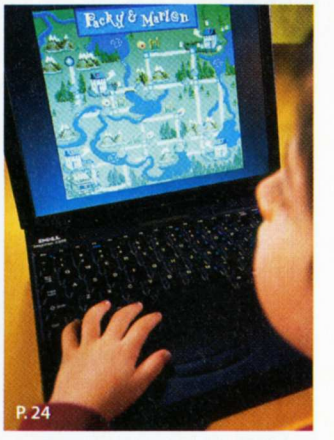
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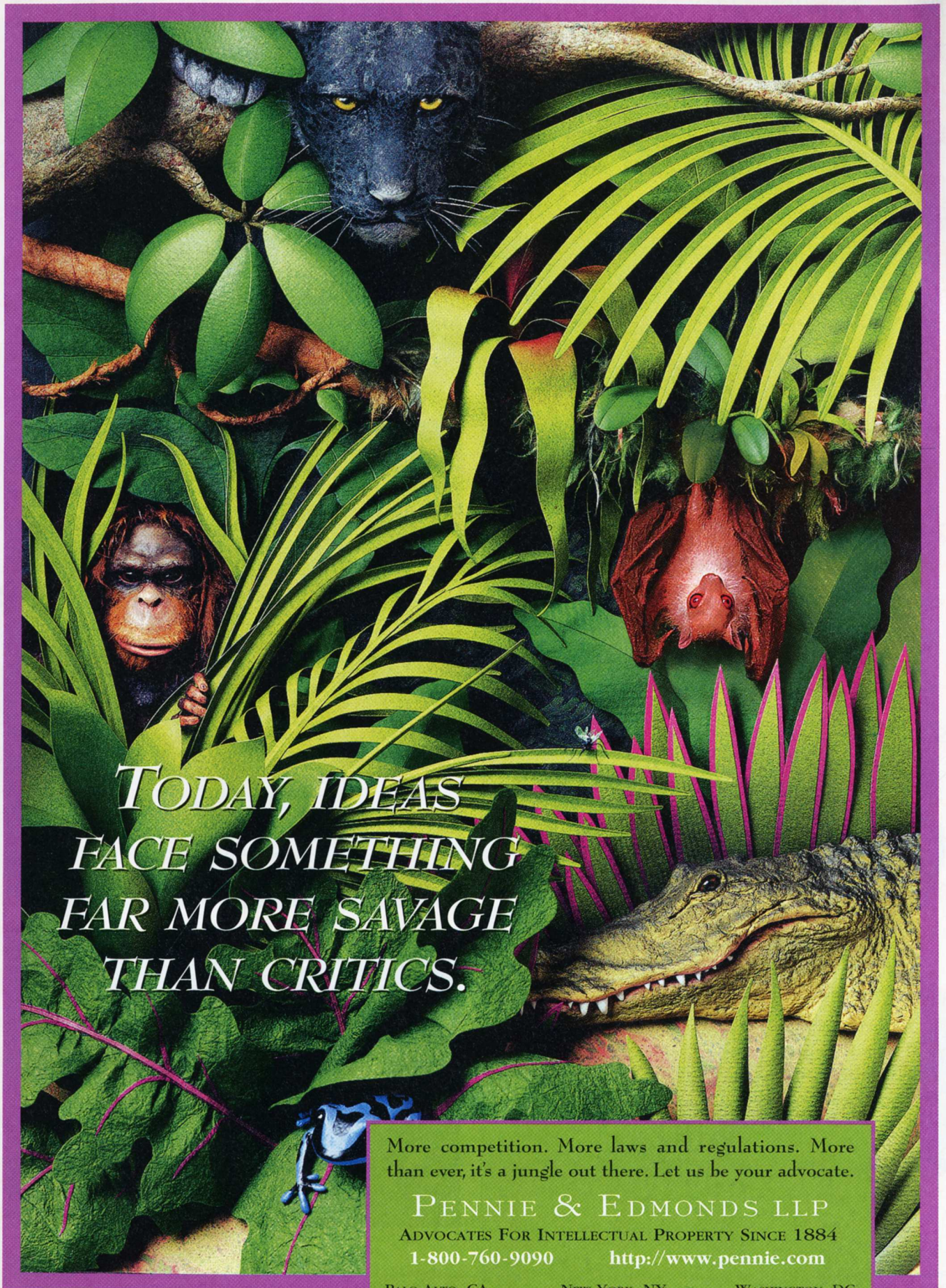


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Inside and Out

SINCE INNOVATION IS THE THEME OF THE NEW TECHNOLOGY REVIEW, IT'S ONLY fitting that we keep innovating here in our own pages—fine-tuning the magazine to bring it to a higher level of excellence with each issue. In this issue we introduce one of a series of steps we're going to take over the next year to improve *Technology Review*'s look, feel and content.

Specifically, we're introducing a new section in the back of the magazine called "Culture Zone." In its new design, by Art Director Kelly McMurray, "Culture Zone" unifies two existing departments and a new one in a "super-department" focused on the intersection of technology and culture.

The two existing departments are "Pages," our book review section, capably written by MIT alumnus Wade Roush, and "Viewpoint," an essay contributed by a rotating group of freelance writers. In this issue the essay is by Daniel Akst, a novelist who lives in upstate New York. He takes on the charged subject of "Selective Luddism"—why we embrace some technologies and fear others, for not very good reasons. The final piece of the new "Culture Zone" puzzle is a new department we're calling "Mixed Media." Replacing the column we called "Web Crawl," "Mixed Media" will provide reviews, not just of Web sites, but of products in many media—movies, software, CD-ROMs, museum exhibits, radio programs and almost any other vehicle for communication.



Because space is at a premium in any magazine, we've had to make tough choices in bringing you "Culture Zone." "Web Crawl," for example, has transmuted into the "Mixed Media" column. And "Under the Dome," a single-page interview with an MIT faculty member, has also changed its spots. Rather than appearing as a single page in every issue, "Under the Dome" will be a series of longer features, on a less regular basis. In its debut in the new format, "Under the Dome" appears as an interview with MIT's Robert Langer—a pioneer in the rapidly advancing field of biomaterials.

While we've been making changes here at home we haven't been neglecting the theme of innovation in the outside world. Our cover package in this issue addresses two remarkably different models of innovation in the world of software. Contributing Writer Bob Buderi offers our readers the first in-depth look at Microsoft's burgeoning research department in an attempt to find out whether the software giant, which has been accused of buying its innovations, can grow its own in Redmond.

We've paired that piece with an article by Charles Mann on the "anti-Microsoft"—the "free software movement." This grass-roots effort, populated by geeks around the world who thrive on giving their work away, may ultimately be the biggest challenge to Microsoft's dominance of the market for computer operating systems. What's fascinating to *TR* is just how diametrically opposed these models of innovation are: tight, centralized control, fueled by billions, versus a completely decentralized movement powered by passion. It will take a while to see which one wins. In the meantime, —John Benditt

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TECHNOLOGY REVIEW

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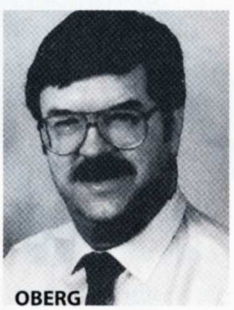
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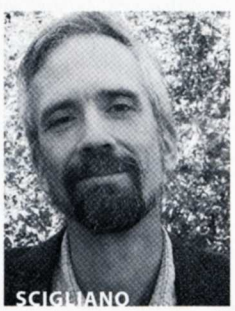
The impending showdown between two dueling computer operating systems—Linux and Windows—is the theme of our cover package. The differences between these two systems go far beyond lines of code. Each is also the product of a unique culture: one a giant corporate monopoly, the other a band of software evangelists who insist that the way to salvation is to give their product away. In "Software's Ultimate Sandbox," *TR* contributing writer **Robert Buderi** assesses the state of innovation at Bill Gates' blue-sky research division, Microsoft Research. Buderi spent three days in Redmond, Wash., interviewing two dozen researchers and managers and learning just how much Microsoft is counting on this free-thinking division to come up with breakthrough technologies.


MANN

In "Programs to the People," **Charles Mann** reports on recent developments in the free software movement, the unofficial network of programmers who create and distribute some of the world's most widely used computer programs. Mann, who lives in Massachusetts with his wife and two children, is a contributing editor at *The Atlantic Monthly* and *Science*, and is the author of *Noah's Choice*, a book about the science of biodiversity. His current book project is a study of world forestry—from the perspective of the trees. Mann is not the only journalist with an unusual perspective to contribute to this issue's pages; "Missionaries to Mars" author **James Oberg** offers the true insider's view. He's worked as an areospace engineer with NASA contractors for 22 years, and counts himself among the Mars junkies who believe the time has come for a manned mission to the red planet. A contributing editor at the Smithsonian Institution's *Air & Space* magazine, Oberg is also the unofficial "statistician to the astronauts" and keeps an authoritative database of space flight factoids. He's holding open the slot for longest manned flight—919 days. To Mars and back. For three years, **Michael Kenward** has followed the field of light-emitting plastics, tracking fits and starts of progress in an area that could revolutionize computer displays and any number of consumer products. In this issue, he zooms in on Cambridge Display Technology, a small British company striving to push their research out of academia and into the market. Kenward, the award-winning former editor of *New Scientist* and one-time fusion researcher, lives in the countryside near Gatwick Airport with his wife and three cats. Former crime reporter **Eric Scigliano**'s fingerprints won't turn up at the scene of a heinous felony, nor are they likely to be on file in the Federal Bureau of Investigation's criminal database—the last time Scigliano was fingerprinted was as a Cub Scout on a field trip to the local police station. But, as the *Seattle Weekly* senior editor discovered while researching "The Tide of Prints," even if he were a killer on file and on the run, it would still probably take the agency more than a month to identify him. Scigliano's work is easier to locate—his writing has appeared in *Slate*, *The New Yorker*, and *Outside* magazine. TR


OBERG


KENWARD


SCIGLIANO

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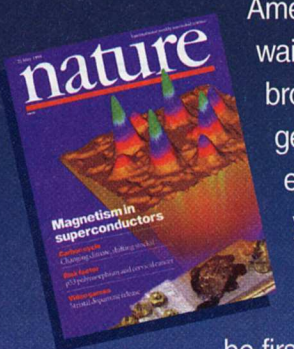


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Leadership in Technology M&A

$9,100,000,000 Bay Networks has agreed to be acquired by Nortel Pending	$1,850,000,000 BERG ELECTRONICS has agreed to merge with Framatome Connectors International Pending	$900,000,000 Stratus has agreed to merge with Ascend Communications Pending	$800,000,000 Texas Instruments sale of DRAM Assets to Micron Technology Pending	$613,000,000 SIEMENS has announced the sale of its SI Defense Electronics Group to a consortium of Daimler-Benz and British Aerospace Pending	$354,000,000 USWEB has agreed to merge with CKS Group Pending
$260,000,000 AMBIT DESIGN SYSTEMS has agreed to be acquired by Cadence Design Systems Pending	ND Lucent Technologies Bell Labs Design Automation Group has agreed to be acquired by Cadence Design Systems Pending	$798,000,000 ARBOR SOFTWARE has merged with Hyperion Software August 24, 1998	$640,000,000 network ASSOCIATES has acquired Dr. Solomon's Group PLC August 13, 1998	$69,000,000 VeriSign has acquired Secure IT July 7, 1998	$9,600,000,000 COMPAQ has acquired Digital Equipment Corporation June 11, 1998
$287,000,000 America Online has acquired Mirabilis Ltd. June 5, 1998	$44,000,000 JDA Software Group, Inc. has acquired Arthur Retail from Comshare, Inc. June 5, 1998	$287,000,000 MoneyGram THE BETTER WAY TO WIRE MONEY has been acquired by Viad Corp. May 22, 1998	$460,000,000 SCOPUS has been acquired by Siebel Systems May 19, 1998	$150,000,000 Healtheon has merged with ActaMed May 19, 1998	$147,000,000 SIEBE has acquired Simulation Sciences May 19, 1998
$300,000,000 network ASSOCIATES has acquired Trusted Information Systems April 28, 1998	$180,000,000 CommQuest Technologies, Inc. has been acquired by IBM March 13, 1998	$464,000,000 Texas Instruments has acquired Amati Communications February 27, 1998	$225,000,000 GEC PLESSEY SEMICONDUCTORS has been acquired by Mitel February 13, 1998	$162,000,000 PRI Automation has acquired Equipe Technologies, Inc. January 22, 1998	$650,000,000 Divingston Enterprises, Inc. has been acquired by Lucent Technologies December 15, 1997
$1,115,000,000 MCAFEE has merged with Network General December 1, 1997	$1,519,000,000 amdahl has been acquired by Fujitsu Limited September 18, 1997	$2,727,000,000 COMPAQ has merged with Tandem Computers Incorporated August 29, 1997	$3,600,000,000 Cascade has merged with Ascend Communications June 30, 1997	$1,180,000,000 hp HEWLETT PACKARD has merged with VeriFone, Inc. June 25, 1997	$8,859,000,000 US Robotics has merged with 3Com June 12, 1997

MORGAN STANLEY DEAN WITTER

Leadership in Technology IPOs

CONVERGYS $195,000,000 Initial Public Offering August 12, 1998	EQUANT $705,486,186 Initial Public Offering July 20, 1998	broadcast.com $51,750,000 Initial Public Offering July 16, 1998	CELESTICA $414,575,000 Initial Public Offering June 29, 1998	i·Cube $34,500,000 Initial Public Offering June 22, 1998	Amdocs $252,000,000 Initial Public Offering June 19, 1998
ACG $57,557,500 Initial Public Offering May 28, 1998	ZD ZIFF-DAVIS $400,000,000 Initial Public Offering April 28, 1998	ARM Holdings plc $131,000,000 Initial Public Offering April 17, 1998	BROADCOM $96,600,000 Initial Public Offering April 16, 1998	RELTEC $183,425,000 Initial Public Offering March 12, 1998	VeriSign $48,300,000 Initial Public Offering January 29, 1998

Leadership in Technology Financings

@Home Network $115,000,000 Common Stock August 12, 1998	EDS $475,812,500 Common Stock August 10, 1998	ASPECT $150,214,400 Zero Coupon Convertible Debentures* August 5, 1998	America Online $549,780,000 Common Stock June 29, 1998	excite $85,050,000 Common Stock June 10, 1998	STMicroelectronics $1,371,562,500 Common Stock June 5, 1998
INGRAM MICRO $460,419,330 Zero Coupon Convertible Senior Debentures* June 4, 1998 $414,000,000 Initial Public Offering October 31, 1996	ARROW ELECTRONICS, INC. $200,000,000 Senior Debentures May 29, 1998	Intuit $462,000,000 Common Stock May 21, 1998	HADCO $200,000,000 Senior Subordinated Notes* May 13, 1998	amazon.com $325,987,100 Senior Discount Notes* May 6, 1998	JDA Software Group, Inc. $105,800,000 Common Stock May 6, 1998
ZD ZIFF-DAVIS $250,000,000 Senior Subordinated Notes April 28, 1998 $1,350,000,000 Senior Secured Credit Facilities April 1998	DELL $500,000,000 Senior Notes and Debentures April 22, 1998	ATMEL $115,004,140 Zero Coupon Convertible Subordinated Debentures* April 16, 1998	CSG $165,080,160 Common Stock April 7, 1998	SAPIENT $91,200,000 Common Stock March 31, 1998	Integral Capital Partners $302,000,000 Integral Capital Partners IV, L.P. March 27, 1998
ASML ASM Lithography NGL 600,000,000 Convertible Subordinated Notes* March 20, 1998 $268,106,250 Ordinary Shares* January 23, 1997	ARBOR SOFTWARE $100,000,000 Convertible Subordinated Notes* March 11, 1998 $35,190,000 Initial Public Offering November 6, 1995	Western Digital $460,129,000 Zero Coupon Convertible Subordinated Debentures* February 11, 1998	network ASSOCIATES $346,150,000 Zero Coupon Convertible Subordinated Debentures* February 10, 1998	Rockwell $800,000,000 Senior Notes January 21, 1998	IBM $700,000,000 Debentures January 6, 1998 $1,000,000,000 Senior Notes and Debentures July 30, 1997
SanDisk $84,000,000 Common Stock November 18, 1997	DOCUMENTUM $71,846,850 Common Stock October 30, 1997 $49,680,000 Initial Public Offering February 5, 1996	APPLIED MATERIALS $400,000,000 Senior Notes October 9, 1997	DASSAULT SYSTEMES $193,864,349 Common Stock September 23, 1997 $179,686,235 Initial Public Offering June 27, 1997	TMP Worldwide $92,000,000 Common Stock September 17, 1997 $67,200,000 Initial Public Offering December 12, 1996	SMART Modular Technologies $154,137,375 Common Stock September 11, 1997

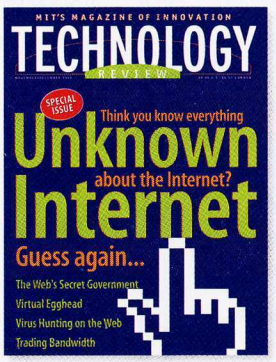
MORGAN STANLEY DEAN WITTER

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"I feel a lot safer with Tim Berners-Lee having the last word on the Web than I would if it were 'managed' by big corporations."

Wise King of the Web?

I FEEL A LOT SAFER WITH TIM BERNERS-LEE having the last word on the Web than I would if it were "managed" by corporate members with the biggest budgets ("The Web's Unelected Government," *TR* November/December 1998).



At least I can use the Web with Linux. Try logging onto MSN with an alternative operating system if you want to experience how the Web could have developed without Tim's insistence on keeping it an open standard. I think we all owe him a big round of applause.

And by the way, isn't it time for an article about Linux? Besides being an excellent operating system, the way it started, grew, and continues to gain users is a good example of people cooperating for their mutual benefit—lessons we all need to learn.

DAVID SMEAD
Ample Technology
Seattle, WA

The editors respond: As far as Linux goes, your wish has already become our command. *See page 36.*

THE SUBTEXT TO SIMSON GARFINKEL'S informative article on the role of the World Wide Web Consortium (W3C) in "regulating online society" is that governance as we know it is changing. Increasingly, our lives are affected as much by the nature of our online experience as by direct actions of the state. And, as Garfinkel shows, that experience can be shaped by protocols and standards established by private entities like the W3C (not to mention corporations like Microsoft). In a sense, they have the ability to make law and policy.

Generally, this is not a problem because most of what these nonprofit organizations do is uncontroversial and, indeed, highly beneficial. Yet occasionally, as in the case of the Platform for Internet Content Selection (PICS), their decisions will spark dissent—and important questions will arise: Do these groups operate in a way that respects openness, accountability and fairness? Is there a rich enough dialogue between technologists and others who care about governance (civil libertarians, consumer advocates, political theorists)? Does the relatively unchecked power of these entities mean that we are privatizing public policy?

To retain their legitimacy, groups like the W3C (and, perhaps even more, ICANN, the new domain name authority) will have to insure that these questions are answered to the satisfaction of Internet users and citizens at large. The key to this, these groups seem to be realizing, is that they must continue to open up their decision-making processes. (The W3C might, for example, invite its critics among the civil liberties groups to join—and they might also waive the $5,000 membership fee.) Moreover, we must all figure out how we can help to create a digital sphere that reflects democratic values and the public interest.

ANDREW L. SHAPIRO
Director, Aspen Institute
Internet Policy Project
Fellow, Brennan Center for Justice,
NYU Law School
New York, NY

YESTERDAY I RECEIVED MY VERY FIRST ISSUE of *Technology Review*. In the very first article I read, I discovered an error. On page 40, the acronym "URL" is defined as "Universal Resource Locator" when in fact the definition is "Uniform Resource Locator." I would expect to see a mistake like this in the *Podunk Daily News* but not in a magazine published by MIT. Typos are one thing, but misinformation is a little harder to explain away. It makes a person wonder if subsequent information can be trusted.

JOE DELASKO
Houston, TX
via e-mail

Garfinkel responds:
The original expansion of URL was indeed Uniform Resource Locator. Universal Resource Locator is the one that is now in common usage. The folks at W3C hate both, and are trying to establish URI, where the "I" stands for Identifier, since the strings identify and do not relocate.

I decided to ask HOTBOT, an Internet search engine, about the various terms. The results:

- Universal Resource Locator appears on 7,942 Web pages.
- Uniform Resource Locator appears on 16,397 Web pages.
- Uniform Resource Identifier appears on 1,711 Web pages.
- Universal Resource Identifier appears on 824 Web pages.

IN MY VIEW, A FUTURE TR ARTICLE SHOULD take a close look at W3C's new meta-data specifications. These are currently in draft state, and merge all the best, and worst, features of both PICS and P3P, but generalize both to being able to handle *any* meta-data, any transactional information, of any kind. The good, and bad, potential of such a standard is enormous, and I agree with the concerns of both the article and several of its quoted commentators in criticizing the public policy role that W3C has, in a sense, simply bumbled into.

My discussions with W3C people like Joseph Reagle, both on and off the record, do not leave me with much hope that W3C will improve itself in this area, either by getting out of making de facto policy, or by being more open and responsive. The few times I've gotten any response from W3C to my criticisms and those of the organization I work for, the answer has generally been something along the lines of, "we don't have a policy-making function, we are simply producing useful technologies

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and it's up to the rest of the world to make sure they are not abused," regardless of what my criticism was.

When I point out that this is a shamefully socially irresponsible attitude, what's the answer? "We don't have a policy-making function, we are simply..." W3C's head appears to be firmly cemented into the sand, and those with concerns about what they are doing are going to have to be a lot more vocal and public with their criticisms, suggestions and concerns in the coming months and years.

STANTON MCCANDLISH
Program Director,
Electronic Frontier Foundation

Disclaimer from McCandlish: This is not an official EFF position, just a personal statement informed by my experience as EFF's program director and by being involved in the issues.

ARE YOU TRYING TO SCARE PEOPLE? IN your recent article "The Web's Unelected Government" you write: "Click into one Web site and you might be completely anonymous; on the other hand, a different site might secretly record your name, e-mail address, and everything you look at." Web site operators cannot get your name unless you provide it to them. Your name is not one of the bits of information that is exchanged during an HTTP transaction (I've read the standards.) It is also unlikely (though admittedly possible) that a Web site operator can get your e-mail address without you providing it. Please don't spread more fear about the Web. People are already paranoid enough without another reputable publication telling them that they're "being watched."

SHAWN PORTER
Rochester, NY

Garfinkel responds:
It's true that the HTTP protocol doesn't send personal information. However, by combining details from cookies, Web site registrations, and other log files, it is actually quite easy to learn a person's name, e-mail address, phone number, SSN and lots of other personal information.

R&D Welfare

G. PASCAL ZACHARY'S PROPOSALS REGARDing government-funded research in 1998 seem to have more in common with the overzealous if not naive Republicanism of 1994 than with a credible, well-formulated blueprint for the future ("End R&D 'Welfare,'" *TR* November/December 1998). But perhaps this misdiagnosis is a natural result of his belief that the purpose of government research is to "spawn entire industries." Publicly supported research is designed to return dividends to the public rather than to investors. Indeed, the real value of of government R&D is its ability to pursue avenues of investigation irrespective of the potential for profit. In addition, much of what Zachary describes as "technology" or "R&D" funding is in fact funding for basic science.

GREGORY J. COST
Department of Molecular Biology
and Genetics
Johns Hopkins University School
of Medicine

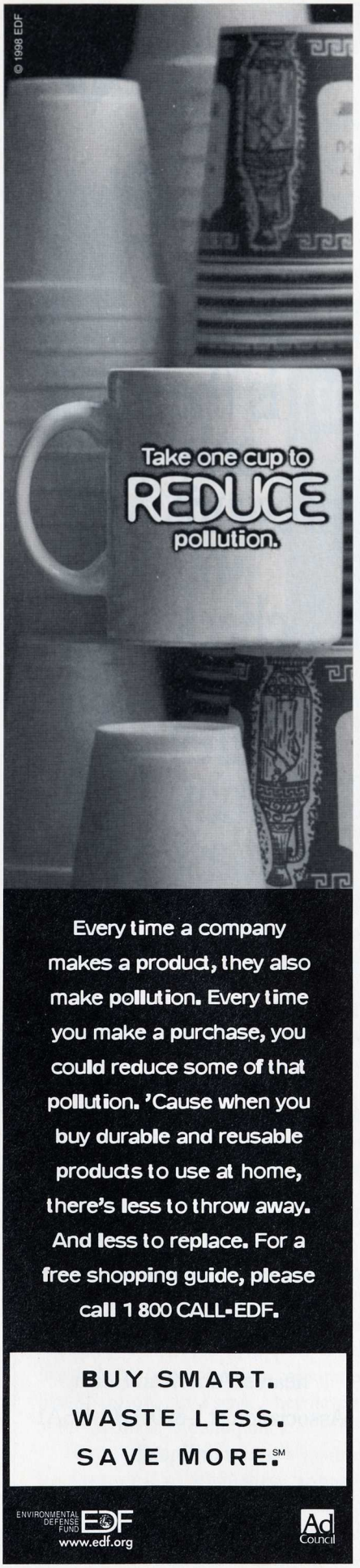
Cost adds: In the interest of disclosure, I feel obligated to report that my position is funded by a grant from the NIH. This is however one of the few agencies Zachary deems fit to praise.

AS AN AEROSPACE ENGINEER SINCE MY graduation from MIT in 1951, I have witnessed the disintegration of the R&D scene from the vantage point of Grumman. I first was involved with naval aviation and then spent six years on the lunar module. The then-and-now comparisons of the agencies involved is exactly as G. Pascal Zachary describes. I am in complete agreement with the Zachary article!

ROBERT W. KRESS
via the Internet

ANY ARTICLE THAT TALKS ABOUT BOTH R&D in one breath is off to a bad start. They're not the same beast, have different roles to play, and are matched to different funding sources. You're doing *research* if you don't know what you're making. Absent government funding, every corporation would simply wait for some other company to do the research. *Development* is when you know what you're making, but you don't know how to do it. There might be some role for government funding here. *Manufacturing* is what corporations are really good at. The government has no business spending money here, and indeed it doesn't spend much. Mr. Zachary lumps these three different beasts into the uselessly broad term "R&D," then applies a dab





of blind faith in entrepreneurial capitalism to end up with an article that mixes truth, confusion and misinformation.

GREG KOCHANSKI
Dunellen, NJ

Art of the (Im)Possible?

I ENJOYED THE INTERVIEW WITH George Whitesides ("Art of the Possible," *TR* November/December 1998) but I think Dr. Whitesides is wrong to say that "[With photolithography] you can't build 3-D things." As counterexample I would point to the creation of semiconductor substrates containing microheat-pipes via the use of repetitive photolithography.

LEWIS R. GOUDY
Los Lunas, NM

INTERESTING ARTICLE AND INTERVIEW. However, Whitesides' statement that there is "no way of realizing" small autonomous machines in the bloodstream due to "horrendous problems with power" is another example of a blanket statement people will strive to invalidate. Novel technology is rarely impossible, it is simply rarely envisioned. Statements like "a human will never break the 4-minute mile. I have measurements to prove it" are bound to get people in trouble eventually.

DAVE TROWBRIDGE
Military Officer, U.S. Army
San Antonio, TX

I WAS PLEASED TO SEE THE INTERVIEW with George Whitesides about nanotechnology but was mystified by his suggestion that autonomous medical nanodevices will be forever infeasible because power, friction or manufacturing pose fundamental obstacles.

Implantable oxygen-glucose fuel cells have been analyzed theoretically and experimentally since at least the 1960s, and future descendants should provide reliable and efficient power inside the human body. *Nanomedicine* (a forthcoming book by Robert Freitas) surveys medical applications of nanotechnology, including the generation of power for medical nanodevices.

Friction poses no fundamental barriers to molecular machinery (see *Nanosystems* by K. Eric Drexler, or my own analysis of molecular bearings, on the Web at nano.xerox.com/nanotech/bearingProof.html).

While it seems likely that many proposed molecular machines cannot be manufactured with today's synthetic technologies, it is also obvious that the ability to position and assemble individual molecular components will extend our synthetic capabilities well beyond the existing bounds and usher in a whole new era in manufacturing. Defining nanotechnology as a simple extension of microtechnology unduly constrains our research horizons.

RALPH C. MERKLE
Xerox PARC
Palo Alto, CA

Crumby Paving

JILL HECHT'S ARTICLE ("WHERE THE RUBber Meets the Road," *TR* November/December 1998) accurately describes "Superpave" as an improved roadway approach. I wonder if some of the millions of tons of used tires could be ground and introduced into the mix, thus saving the atmosphere from the pollution produced by the common disposal method of used tire incineration.

A.C. GERMANN
Mt. Shasta, CA

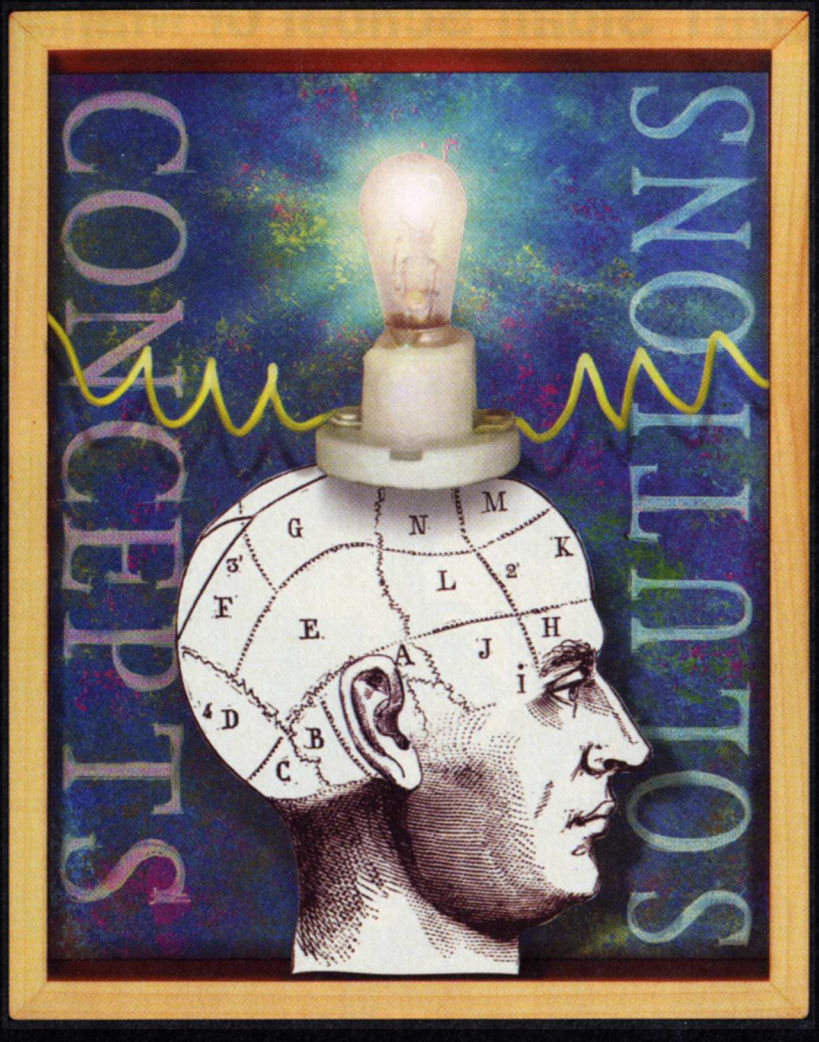
AS A RETIRED HIGHWAY ENGINEER WHO worked where the rubber meets the road, that is, actually building and maintaining roads, I commend Jill Hecht's efforts. In 1968 we experimented with crumb-rubber-enhanced asphalt for increased durability. It worked extremely well and lasted a long time but was initially more costly.

It is truly unfortunate that decisions to use any design are all too often made by those who have little understanding of the technology. Initial cost too often governs the selection of the design. Material suppliers whose product requires an additive usually lobby very successfully to prevent requirements so they can compete in the initial cost marketplace. Until endurance or guaranty requirements are added to the construction projects the public will continue to be shortchanged and not get their money's worth.

JOHN W. LIVINGSTON
via the Internet

Correction: *In the article on W3C,* ("The Web's Unelected Government," *TR* November/December 1998*) the name of the Platform for Internet Content Selection (PICS) was misstated. The editors regret the error.*

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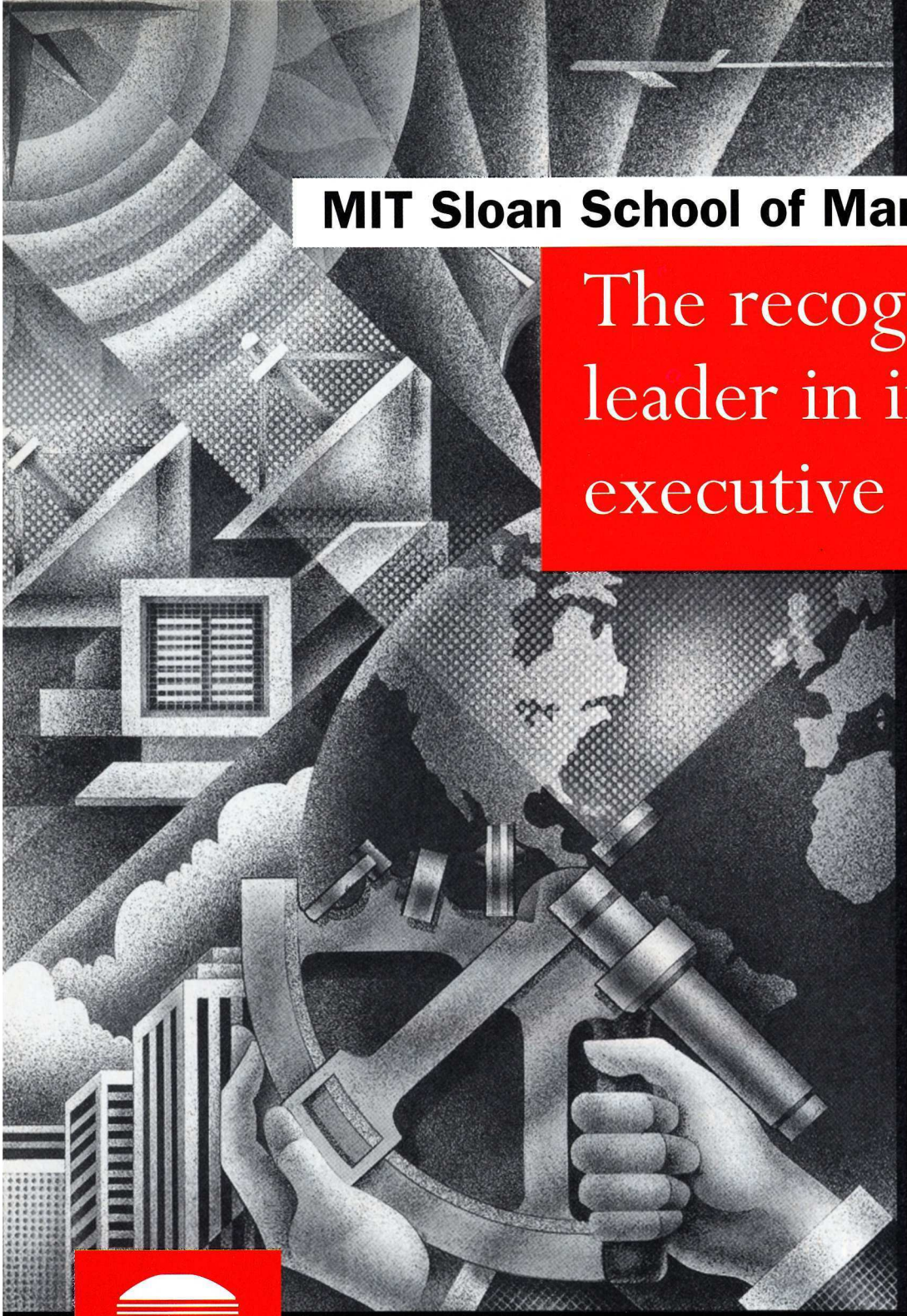
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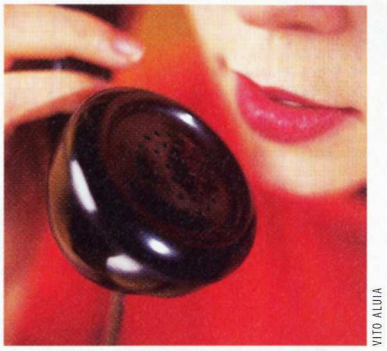
Germ-Killer Cosmetics

Imagine fending off the flu with a quick nasal spray. That may one day be possible, according to researcher James Baker at the University of Michigan Medical School.

Baker found that a mild, milky liquid called BCTP killed the influenza virus in cell cultures and in the nasal passages of lab mice. Craig Wright, chief research scientist at Columbia, Md.-based Novavax—the company that developed BCTP—explains that the liquid destroys viruses and bacteria by selectively disrupting their membranes without harming human cells. Wright says substances like BCTP—a nanoemulsion of lipids—are much like skin moisturizers: "I like to call them killer cosmetics."

Baker says his team hopes to begin clinical trials of the anti-microbial agent "in a couple of years," and they're investigating the use of BCTP to neutralize biological weapons such as anthrax.

Master's Voice



VITO ALUIA

Sometimes, slogging through bloated Web sites to find a piece of information can make you wonder whether all the clicking and typing are worth the trouble. Wouldn't it be nice just to ask a question out loud, have the computer fetch the nugget of data you request, and then recite it back to you in plain English? That's what you get from an experimental system that Naperville, Ill.-based Spyglass has devised in collaboration with Lucent Technologies. Dial up the phone and ask your question, e.g.: "What's today's weather in Chicago?" After Lucent's voice recognition software decodes the utterance, the Spyglass "Prism" system goes into data-mining mode. In this case, Prism identifies and retrieves just the data you asked for from www.weather.com—ignoring the megabytes of extraneous data at the site that would distract a surfer. Similar arrangements with other sites will permit quick-and-easy retrieval of, say, stock quotes, or sports scores. The phone browser is at least 18 months from commercial introduction, says Maia Tihista, director of corporate marketing at Spyglass.

New Green Revolution



ANNE-MARIE STOMP

Can an innocuous aquatic plant manufacture disease-curing proteins? Drug companies already use genetically engineered bacteria to produce therapeutic proteins such as Factor IX, a blood component that hemophiliacs lack. Others are trying to insert genes into the cells of animals so that the animals can produce specific proteins in their milk.

Anne-Marie Stomp, a professor of forestry at North Carolina State University, says humble duckweed could best both bugs and beasts. The tiny plant may top animals because it is "clonal"—it buds off copies of itself—which means genetic changes will stay intact in succeeding generations. The fast-growing plant can produce more sophisticated proteins than bacteria, says Stomp, and can thrive in an industrial setting. Stomp has started a company, Biolex, to teach the plants to secrete proteins for easy collection.

Balancing Act

Thousands of Americans with untreatable inner-ear problems suffer from a severe lack of balance that can make something as simple as getting out of bed a nightmare. Now it seems the technology used to orient airplanes and satellites could help these people regain stability.



DRAPER LABORATORY

Scientists at MIT and Draper Laboratory are developing a tiny gyroscope and accelerometer that patients with balance disorders could wear as a headset. The instruments send a signal to vibrational devices the size of M&Ms sewn into the patient's clothes. When the person leans more than 10 degrees from the vertical, the devices on that side vibrate, producing a sensation that prompts the wearer to straighten up. Tests on patients with balance disorders are beginning at the Massachusetts Eye and Ear Infirmary and Massachusetts General Hospital.

Smell-O-Vision



MYRON W. KRUEGER

Stinking sulfur. Sweet peppermint. Sweat. These are the smells of Myron Krueger's laboratory, where virtual reality is taking on a new aroma. Krueger has built an olfactory display system—the nasal equivalent of the head-mounted displays used for visual effects. The portable device dispenses scents from bottles of liquid odorants; tubing carries the vapors to the nose.

Smell's evocative qualities could make virtual reality more convincing, and might help in simulations where odors are an important cue—such as training paramedics or doctors. Krueger's company, Artificial Reality (Vernon, Conn.), is working with a grant from the Defense Advanced Research Projects Agency, which hopes to add "telesmell" to battlefield telemedicine. Krueger, an early pioneer of virtual reality, says the main bottleneck lies in synthesizing smells. While the perfume industry has mastered the ability to produce floral and fruit fragrances, less is known about how to concoct many less pleasant odors.



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LOCKHEED

Second Skin

If you have ever struggled to laminate an identity card, just imagine laminating a jet airliner. But that's just what engineers at 3M are doing, in a bid to replace environmentally unfriendly paint with adhesive films. Funded by the U.S. Department of Commerce, 3M has tested hundreds of materials to find polymers and glues that can stand up to jet fuel, hydraulic fluids and supersonic speeds. According to 3M project manager David Hoyle, the fluoropolymer film now in advanced testing with Boeing and Lockheed is proving easier to use than paint, which must be applied and removed in a special hangar; the Teflon-like polymer may last longer as well. 3M is also exploring drag-resistant films, and polymers with stealthy properties for military craft are probably not far behind. Hoyle says the tough skins may soon find their way onto interstate road signs and possibly automobiles.

Sunny Talk

Cell phone users worry constantly about dwindling battery charge. To eliminate that concern, AstroPower Inc., of Newark, Del., is trying to build a small array of crystalline silicon solar cells linked like circuit elements on a microchip. This "monolithic" connection permits a large number of cells to be hooked up in series—stepping up the voltage to the required level without introducing the electrical resistance that ordinary wiring would produce.

Unlike the amorphous silicon used in calculators, the crystalline devices require sunlight—not indoor fluorescent illumination—to generate electricity. Still, says AstroPower's Lou Dinetta, a roughly 2.5-by-5-centimeter array would supply enough power for an hour of talk time. Wearing the cell phone on the hip outdoors would expose it to enough sunlight to maintain the phone in standby mode indefinitely. AstroPower is negotiating with at least one major cell-phone maker.

Pest Test

A bacterial protein called Bt toxin makes a safe and effective pesticide. But Bt-proof bugs could render the agricultural resource useless. So researchers at North Carolina State University are helping to develop a test kit that gives farmers early warning of Bt resistance, allowing them to give the affected area a break from Bt before a "super pest" emerges.

NC State entomologist R. Michael Roe calls the testing technique "embarrassingly simple"—a farmer merely adds water and a bit of Bt to wells in a cellular-phone-sized container, then drops in a few bugs from the field. Each well holds insect food mixed with an indicator dye that turns bug feces blue. Bt-susceptible pests sickened by the toxin don't eat—and therefore don't defecate. But resistant bugs produce blue droppings—a quick, colorful warning for the farmer, who would otherwise have to wait a week or so for the insects to die. A large-scale field study of the test kit, sponsored by Cotton Inc., should be completed this spring.

Digital Dustbuster

Remember when hisses and pops were part of the audio experience? Fewer and fewer people do, now that CDs have made near-perfect sound reproduction commonplace. But technology has not been as kind to our eyes. Dust, scratches and fingerprints continue to mar photographic film. Fixing these images now requires either tedious manual touch-up of the negative or slide, or electronic processing that alters the underlying image.

Austin-based Applied Science Fiction has devised a way to erase these flaws. The technique relies on a film scanner's ability to focus precisely on each dye layer. The system produces separate signals for the yellow, magenta and cyan layers. A fourth "defect channel" is derived from light focused on the film's surfaces. A proprietary algorithm applies this correction to yield a clean electronic image within a few seconds. Nikon has licensed the technology for its film scanners.



APPLIED SCIENCE FICTION

Sorting on the Rebound

Looking at all the recycling bins on curbsides these days you'd think the manufacture of new plastic must be dwindling. Not so—increases in production of virgin plastic packaging outpace the gains in plastic recycling by an order of magnitude. One reason is the difficulty recyclers have in separating various kinds of plastic; if they're mixed, the whole batch is useless. But researchers at SpectraCode of West Lafayette, Ind., have invented a point-and-shoot device that could solve the problem.

The system shoots a laser beam at the plastic, then analyzes the light reflected from the surface. The distribution of wavelengths serves as a "molecular fingerprint" identifying the type of plastic. The device can distinguish most kinds of plastic in 10 microseconds, which when automated could mean 500 tons of plastic per day in a typical recycling operation. The system's utility goes beyond plastic: Researcher Ed Grant has used it to distinguish between various kinds of flours and sugars.



VITO ALUIA

The Rich People's Computer?

THE INFORMATION GAP BETWEEN RICH AND POOR in the world is difficult to assess. For example, it took me three months to find out from a perplexed Bangladeshi embassy official in Washington, D.C., what fraction of their economy is devoted to hardware and software products and related services. He finally calculated the fraction at one-tenth of 1 percent. In the United States, the corresponding figure is 100 times larger—fully 10 percent of our economy goes to information technology. Since the average Bangladeshi is 30 times poorer than the average American, the disparity, per person, between our annual expenditure on information technology and theirs is even more staggering—on average, $3,000 for each American, versus $1 for each Bangladeshi!

I suspect that if I could locate an "embassy" representing poor Americans, I would find an equally screeching dissonance between information technology expenditures in the inner city and the suburbs. It stands to reason that people struggling to get their daily bites of food have nothing left for the more ethereal bytes of information. Take this disparity to its logical next step: The rich, who can afford to buy the new technologies, use them to become increasingly productive and therefore even richer while the poor stand still. The conclusion is as logical as it is inescapable: Left to its own devices the information revolution will increase the gap between rich and poor nations and between rich and poor people within nations.

Some experts, including Bill Gates, argue that the new technologies will help the poor become literate, learn how to plant new crops, take care of their health and sell their services over an expanding information marketplace. His view is consistent with my own, subject to one big "if": The poor could have a chance of reaping these benefits, if they were somehow provided with the communications systems, hardware, software and training needed to join the club. Absent such help, they can't even get started.

It's time we begin providing this help, not just to be compassionate but also to avoid the bloodshed that, historically, follows a widening rich-poor gap.

Fortunately, there are things we can do to help: Communications could be provided by low earth orbiting satellites (LEOS) that whip around the earth: When these birds are over the wealthy industrial nations they are very busy, but when they are over the developing world, they are doing nothing. Let's pay the low marginal cost to leave them on. Manufacturers of hardware and software systems and providers of training, terrestrial communications and other such services could offer their goods to the poor at very deep discounts. If we, the citizens of the rich industrial nations, truly want to help, we can pay the cost by instructing our governments to offer attractive tax breaks to these suppliers. The suppliers, too, could share the costs, since an expanding information marketplace will mean more business for them. Individuals could help with donations of funds and of their time. And organizations such as the World Bank, which spends more than $15 billion annually in structural loans to the developing world, could make a big difference by putting some of these funds into bytes-to-bites projects.

Stimulated by these exciting prospects, a few of us techies got together with a colleague from Nepal, fully expecting to boost his nation's economy by 20 percent through clever use of the information marketplace. Unfortunately, we quickly found out that even if we got the communications, hardware, software and training for free, we would still fall short of our goal: Only 27 percent of the Nepalese are literate. And of these, only a small fraction speak English. When we asked what services that smaller group could offer, we hit a brick wall. Many are not skilled, and those who are are already busy running their nation's businesses. Maybe we were too ambitious when we envisioned a future workforce in Nepal selling office services to New York and London via the Web. What if we focused instead on selling Nepal's famous crafts, like custom-made rugs, on the Web? That got us into all sorts of other concerns about establishing trust among distant buyers and distributing the goods. The potential of the modern information age seemed overshadowed at every turn by the ancient forces that separate the rich from the poor.



We have already overcome great challenges to construct the modern computer. Yet this technological marvel interconnects only 1 percent of the world's 6 billion people.

Are such difficulties reason to give up and leave the information revolution to its own devices? No! We should persist, because the information marketplace is huge and largely unexplored. If even a small number of Nepalese or a few inner-city people found a way to become productively interconnected, they would serve as role models to their peers. Readers are invited to suggest creative ways in which the poor could become productively engaged in the information marketplace.

We have overcome great challenges to construct the modern computer. Yet this marvel interconnects only 1 percent of the world's 6 billion people. It is, in effect, the rich people's computer. For our own and our fellow human beings' welfare, we should now go after the tougher challenge of turning our proud achievement into the people's computer! ◊



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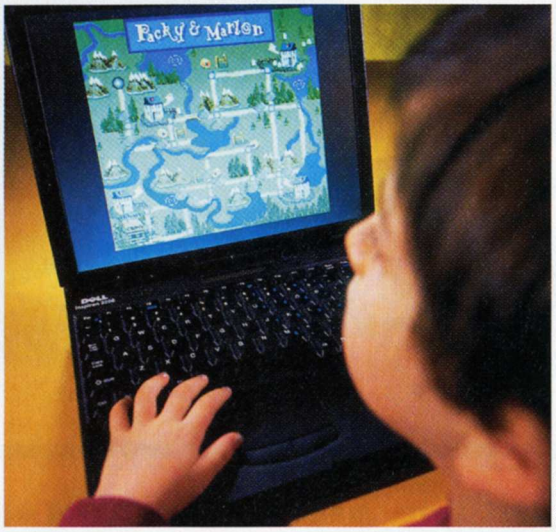
EDUCATION

Click for Health

Play two video games and call me in the morning

VIDEO GAMES PROP OPEN A DOOR in kids' brains, creating an opening through which knowledge can march with almost no resistance. Game-playing children absorb enormous amounts of information and develop outlandishly high skill levels. Trouble is, virtually none of what they learn has any value beyond the joystick and glowing screen.

But medical researchers are also exploiting the magical power of video games to convey useful information. Recent findings provide compelling evidence that the right games can train kids with diabetes and asthma to keep their conditions under control.



VITO ALUIA

Researchers at Stanford University Medical Center worked with about 60 kids aged 8 to 16 suffering from diabetes. The children were given a video game to take home. Some got an ordinary game, such as *Tetris;* the other half took home a specially designed game, called *Packy & Marlon,* in which two elephants try to survive on an outing by collecting food in a simulated environment—all the while remembering to check their blood glucose and administer insulin to themselves.

The result: Over the study's six-month period, the kids who played *Packy & Marlon* needed 77 percent fewer urgent-care visits to a doctor or emergency room than the kids who played the placebo game. The researchers told kids in both groups to play their games as much or as little as they wanted. The study reports that the children spent about the same amount of time playing *Packy & Marlon*—about 1.5 hours a week—as the control group devoted to the noninstructional game.

Another game from the same company that makes *Packy & Marlon*—Mountain View, Calif.-based Click Health—teaches asthma sufferers the basics of how to keep breathing well. Year-long trials of *Bronky the Bronchiasaurus* are under way with 200 asthmatic kids—half in Oakland and half in rural Washington state.

In *Bronky,* players have to maneuver a dinosaur hero through a standard-looking video-game-style world, picking up treasures and stomping on enemies as the screen scrolls horizontally. Multiple-choice questions pop up on the screen, interrupting the action by quizzing the player on tactics for avoiding asthma "triggers" and on the proper technique for measuring one's own "peak flow." After a wrong answer, the game directs the player to find Hazel, a character who will re-teach basic asthma-care techniques.

Next up from Click Health will be an electronic pet, similar to the wildly popular Tamagotchi, that will help teach kids with cystic fibrosis how to keep their often fragile bodies in the best possible working condition. Another game could aid children with sickle-cell anemia, says Click Health's founding chairman and CEO Alan Miller, who previously founded two successful video-game companies, Activision and Accolade.

The effectiveness of video games in teaching real-life skills to children cuts both ways, says one new-media researcher. "People are always asking about the negative effects of video-game violence," says Georgia Tech professor Amy Bruckman. Showing that Click Health's games can change kids' behavior for the better also accentuates the concern that violent games are equally effective at imparting their less benign lessons, Bruckman says.

—Herb Brody

BIOMEDICINE

Stem Cell Hunters Capture Their Prey

The human embryonic stem cell, which could be used to grow any other human tissue, has been a stubborn and elusive prey *(see "The Troubled Hunt for the Ultimate Cell," TR July/August 1998).* Now, in the scientific equivalent of a photo finish, two teams have announced, in *Science* and *Proceedings of the National Academy of Sciences,* respectively, the isolation of stem cells from human embryos. Their results could have very significant implications for biological research and transplant medicine.

The race was complicated by a ban on federal funds for embryo research and opposition from pro-life groups. As a result, funding has come from the private sector. Indeed, both winning groups, one led by James Thomson of the University of Wisconsin, the other by John Gearhart of Johns Hopkins University, had financial backing from Geron Corp., a biotech company in Menlo Park, Calif.

Though the race for the ultimate human cell may be over, the story isn't. Researchers are likely to tangle for rights to claim the discovery—and patent applications already filed by other teams could complicate the picture.

—Antonio Regalado

University Venture Funds*

INSTITUTION	FUND AMOUNT ($, MILLIONS)	YEAR CREATED	FUND NAME
Boston University	25	1998	Photonics Venture Partners
Cleveland Clinic Foundation	20	1998	Novamedics
North Carolina State University	10	1998	Centennial Venture Partners
U.K. Medical Research Council	50	1997	UK Medical Ventures Management
Vanderbilt University	10	1998	Unnamed

*Includes recently formed funds at research institutions and universities; specific relationship to institutions varies.

FINANCE

Intellectual Capital

Universities jump into the venture game

At a symposium at the Boston University (BU) Photonics Center this fall, the attendees broke for coffee as usual. But something was amiss. Instead of professors munching cookies and chatting about the latest research, men in suits stood facing blank walls, whispering into cell phones. They are high-powered investors, but they're not from Silicon Valley—they're from the research center's ninth floor.

Better toss out the old stereotypes about academia and get with the latest rage—ivory tower goes venture capital. Bidding to spin off more technologies, boost local economies, and just plain make money, many research institutions and universities are creating their own venture capital funds.

Venture capital has traditionally been the domain of private, deep-pocketed investors hoping to earn a windfall, often by picking off promising university research. Most of the action has centered around big-name schools, such as MIT and Stanford University, located near East and West Coast hubs of venture capital. But now an increasing number of universities around the country want their piece of the pie—and are willing to do what it takes to get it.

The latest example is BU's Photonics Venture Partners. The fund is privately managed, but the university is both an investor and a manager—one of the firm's three general partners is Donald Fraser, also the Photonics Center's director. Working cheek-by-jowl with BU researchers studying blue lasers and quantum communication, the venture capitalists plan to leverage the center's technical acumen to invest in the rapidly growing field of photonics.

No two of the university funds turned up by a *TR* survey *(see table)* are exactly alike. Some are wholly-owned subsidiaries, others are independent firms awarded preferential rights to an institution's technology. They also have varying aims. At BU, the strategy is to invest in any photonics company likely to return a profit. At Vanderbilt University, on the other hand, administrators just christened a $10 million fund that will invest in companies built around the school's technology.

Larry Steranka, Vanderbilt's director of technology licensing, says the main reason for the do-it-yourself funds "is that many promising university inventions are simply too early-stage and too risky to interest mainstream venture capitalists."

But based on a study of schools that have previously tried venture funds, Josh Lerner, a professor at Harvard Business School, thinks university administrators often have unrealistic expectations for financial success. Lerner thinks they also underestimate the challenge of combining the quick-to-move venture culture with rule-bound academia. "It's very hard to marry these organizational forms," says Lerner.

—Antonio Regalado

MINING

Harvest of Gold

Gold miners aren't going to want to throw away their drills and explosives—at least, not right away. But in New Zealand, researchers have come up with another way to mine gold. It's a plant, *Brassica juncea,* that is in the same family as cabbage.

No one is likely to strike it rich using this floral method, says Robert R. Brooks, a geochemist at New Zealand's Massey University who trained the plant in gold mining. But it could provide an effective way to glean gold from the "tailings," or spent earth, around old mines.

The New Zealand scientists added to the soil the compound ammonium thiocyanate, which binds to gold particles, forming a water-soluble complex that is transported through the roots and gathered in the shoots and leaves. The dried plants can be incinerated, leaving small flecks of ore in the ash.

Brooks is prospecting for other plants that can absorb gold even more efficiently. He speculates that the technology of induced accumulation might also be applied to collect silver, platinum, palladium and other precious metals.

With the price of platinum even higher than that of gold, it just might be time to get out the rototiller and expand that garden this spring.

—David Graham



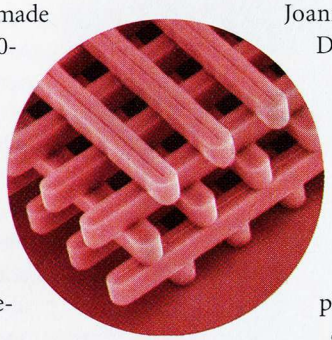
MARIS BISHOFS

PHOTONICS

Right on (Infra) Red

Breakthrough in optical telecommunications

CAN LIGHT TURN SHARP CORNERS? Pierre Villeneuve and John Joannopoulos say yes. After nearly a decade of theoretical calculations, the two MIT physicists believe they—and collaborators at Sandia National Laboratories in New Mexico—have made light efficiently navigate a 90-degree bend in an optical material called a photonic crystal. This path-breaking research could lay the groundwork for an entire new generation of telecommunications devices, as well as integrated optical circuits.



SANDIA NATIONAL LABORATORIES

Sandia's 3-D photonic lattice.

Generally, light doesn't like being tamed. Unlike electrons that can be easily routed (a fact that makes the world of electronic devices possible), photons are difficult to direct. It's one thing to shoot light out in a straight line, but try and bend it around a sharp corner and light scatters wildly. As a result, existing photonics devices used to bend light at a 90-degree angle are bulky and inefficient.

The nature of light has set some strict limits on current optical devices. Light traveling through optical fibers has revolutionized telecommunications, but you still need electronics at each end in the twisty little circuits that process the signals. To make lightwaves do the twists and turns that would be required in optical circuits—and eventually in the optical computers envisioned by physicists—you need precise control.

Sometime within the next several months, researchers at Sandia, working with the pair of MIT theoretical physicists, expect to finish building and testing a tiny photonic crystal that will allow them to bend and twist light at the wavelengths used in telecommunications and many optical devices. It could give scientists control over light to an extent never before possible and could be the building block of everything from microlasers to optical integrated circuits. It would mean "that we can bend light like a roller coaster. The devices that then could be realized are up to your imagination," says Shawn Lin, the Sandia electric engineer who is building the crystal.

"What's exciting to me, and what has been right from the beginning," says Joannopoulos, Francis Wright Davis professor of physics at MIT, "is that I saw photonic crystals as providing a new mechanism to control and manipulate light." Photonic crystals are opaque to certain wavelengths of light. But photons can travel along defects in the crystal. By creating a linear defect in the crystal, Joannopoulos reasoned, it would be possible to route the light along that path.

That's the theory. And, in fact, it works. Building such a device, however, is not easy. Last summer, Lin and his Sandia co-workers took a step forward by fabricating a 3-D photonic crystal that works with infrared light at wavelengths of 10 micrometers—it was the smallest photonic crystal ever made but still too large to work with the 1.5-micrometer wavelengths of light used in telecommunications.

Then, last fall, Lin and the MIT scientists collaborated to bend microwaves (which have wavelengths on the centimeter scale) at a 90-degree angle with nearly 100 percent efficiency. The results, published in *Science*, involved wavelengths much larger than the targeted 1.5 micrometers but proved Joannopoulos' theory that photonic crystals could be used to guide light around corners.

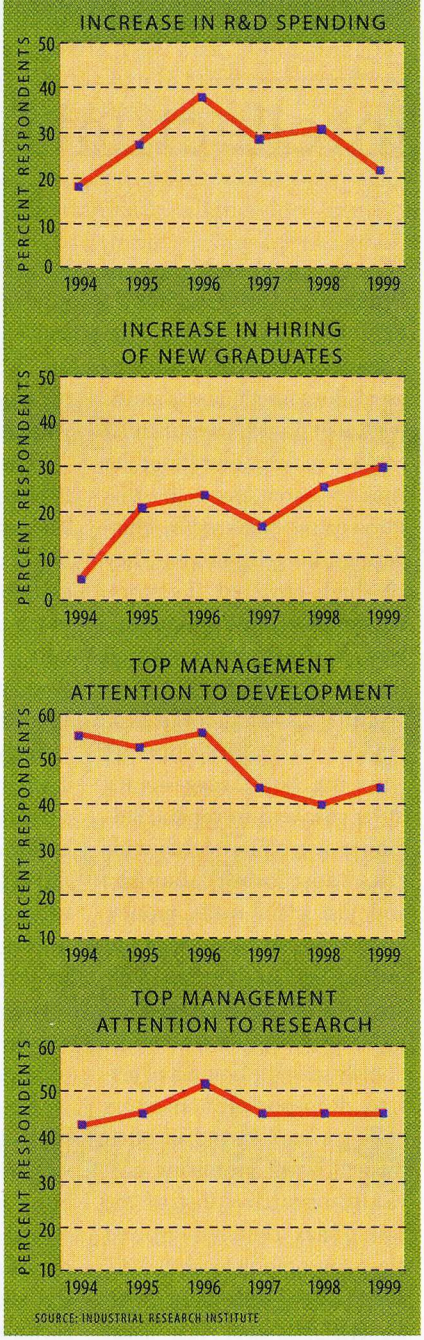
Now it's a matter of shrinking it all down to make a device that can bend light at around 1.5 micrometers—the really interesting commercial wavelengths. Lin points out that such a photonic crystal must have features at the scale of 100 nanometers (billionths of a meter) and must control the light in three dimensions. "It's very difficult but it can be done. We're on the verge of a breakthrough," says Lin.

—David Rotman

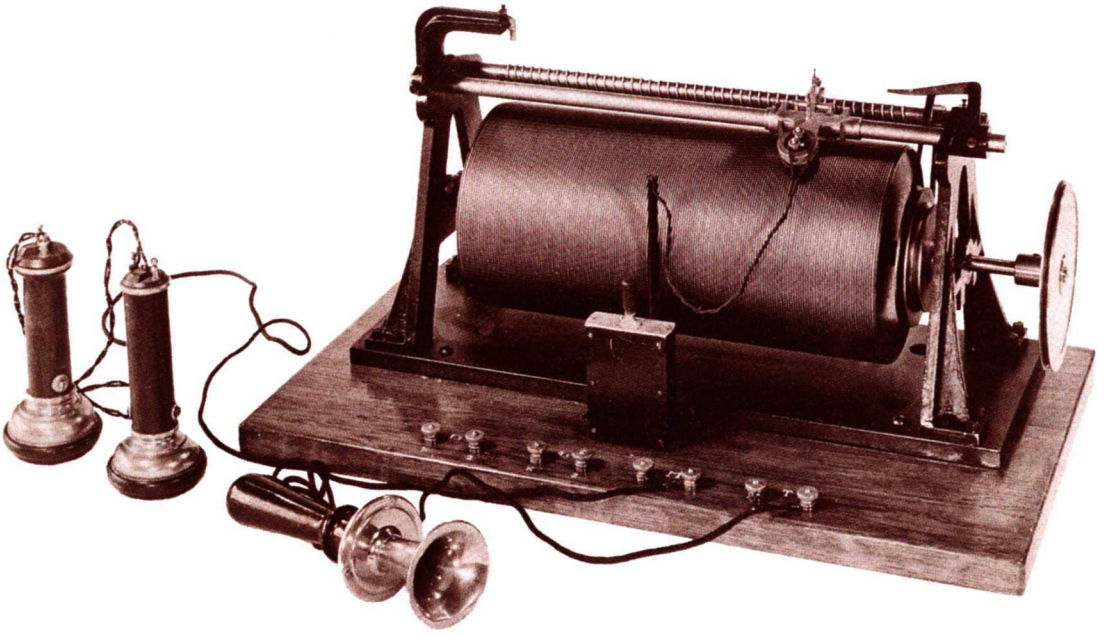
R&D FUNDING

Tight Research Dollars Ahead

As we enter 1999, the mood of top U.S. industrial research managers is one of caution. Expenditures for R&D will keep rising but the increases will not be as sharp or as widespread as they were during the last few years, according to the annual survey of the Industrial Research Institute (IRI) in Washington, D.C. Each graph below shows the percent of IRI respondents expecting increases of more than five percent.



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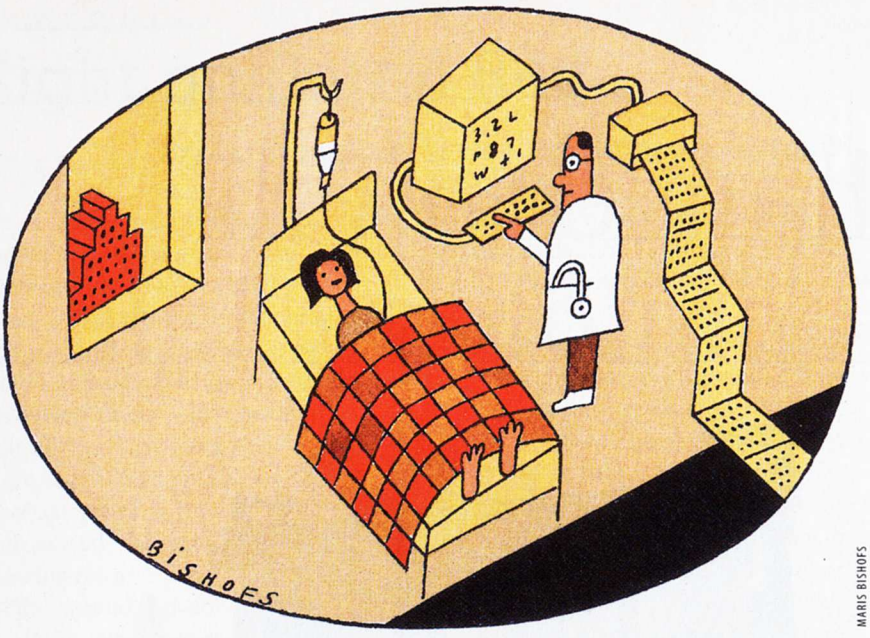
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MARIS BISHOFS

INFORMATION TECHNOLOGY

Raising the IQ of Critical Care Units

A smarter way to monitor patients

ANYONE WHO HAS RECENTLY KEPT A bedside vigil in a hospital's intensive care unit (ICU) is likely to have been impressed by just how much information is now gathered on a critically ill patient. Sophisticated monitors surround the bed, the electronic screens spewing out a torrent of data. That information can be vital, particularly for those near death. But it also poses a critical challenge for today's hurried nurses and physicians: how to make sense of all that data.

To help out, researchers at the University of Pennsylvania Medical Center are testing a "smart" ICU technology that collects and analyzes a patient's vital signs. The artificial-intelligence system produces a 3-D graph that could make it easier for a clinician to quickly pick up any warning signs. The smart ICU uses adapted off-the-shelf software for neural networks and fuzzy logic that allows it to analyze several measurements simultaneously, looking for dangerous trends; it can also "learn" the patterns of a patient, including their ideal vital signs.

"It's not intended to replace a physician," says C. William Hanson, section chief of anesthesia/critical care at the medical center and developer of the technology. "It's intended to act as an intelligent assistant that's vigilant." Patients in the ICU, says Hanson, are "monitored for everything we can monitor electronically, and there's very sophisticated minute-by-minute information" on everything from respiratory rates to blood flow. But actual analysis of the data "is, in reality, totally unsophisticated," says Hanson. "There's hidden information in a lot of that stuff."

By uncovering that information, the smart ICU will, if it works, flag dangerous conditions soon after they develop. For example, says Hanson, blood accumulating around the heart can be a serious problem for some patients, but it's often not noticed until the individual's blood pressure significantly falls. In fact, there are early warning signs, including a series of interrelated, predicting signals, such as a drop in blood pressure and an increase in heart rate. While "a really good clinician" would likely notice those indicators, says Hanson, that "presupposes that there's a really good, experienced clinician—and that they're at the bedside."

Preliminary real-life tests of the system are under way. Hanson notes that the medical center's ICU is already installing a PC at every bedside that will collect information from the monitors and act as an electronic spreadsheet. "In the world of information technology, that's a fairly trivial thing to do," says Hanson. "There are a lot more interesting things the PCs can do. There's still a lot of smartening up that can go on in the ICU."

In today's busy hospitals, a more intelligent ICU can only be a good idea.

—David Rotman

GLOBAL POSITIONING

Really Remote Sensing

Mapping land ownership in coastal Nicaragua

WALKING FOR HOURS THROUGH pouring rain, chest-high water and dense forests, people living on Nicaragua's Caribbean coast are using GPS (the global positioning system) to create the first-ever maps showing land claims in their remote region.

The inhabitants of the resource-rich area include indigenous peoples and mixed-race, Spanish-speaking Mestizos. But no one has ever mapped the communities' borders in detail, and as economic pressure mounts to develop and exploit the area's resources, the ownership issue has become critical.



PETER H. DANA

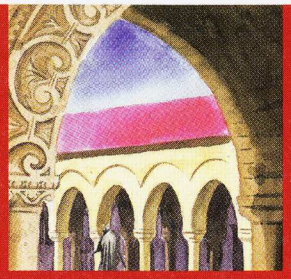
Preliminary maps show land use.

As a first step toward formalizing land rights, the Central American and Caribbean Research Council, an Austin-based non-governmental organization, collaborated with Nicaragua's Center for Investigation and Documentation of the Atlantic Coast, to use GPS technology to spell out the claims of each of 127 local communities. To create the maps, members of the communities used GPS to document the position of familiar landmarks, such as trees or crossroads, that form traditional boundaries. At the same time, the local volunteers gathered information about current and historical land use to back their claims. Position data were recorded in waterproof yellow notebooks and later entered into an electronic spreadsheet. The researchers overlaid the GPS-based boundary information and related land-use data on a conventional topographic map.

The researchers chose inexpensive and relatively inaccurate hand-held GPS receivers. The low price made it possible to buy more of them and map the land more quickly. And according to Peter Dana, the project's geographer/cartographer, the easy-to-use units also made the process more open. "Everyone assumes that you need the highest possible precision at any cost, but what that means is that only trained surveyors can produce the data and the maps," says Dana.

In addition, he adds, higher levels of precision would actually have interfered with the process: "If we'd done real-time kinematic surveying to centimeters, we would have had to make thousands of position measurements along contested boundaries. Folks could easily dispute them and feel that they had to defend them or fight for them in some way."

Preliminary maps were completed and delivered to the government in June 1998. However, these maps are only a first step in preparation for the long and complicated political and legal process of establishing land titles. Other hurdles include reconciliation of overlapping claims between communities, follow-up mapping, and creating resource management plans. But in a place where land ownership battles can turn violent, the initial success of the GPS project could foretell more peaceful resolution of land disputes and stronger claims for the locals. **—Deborah Kreuze**



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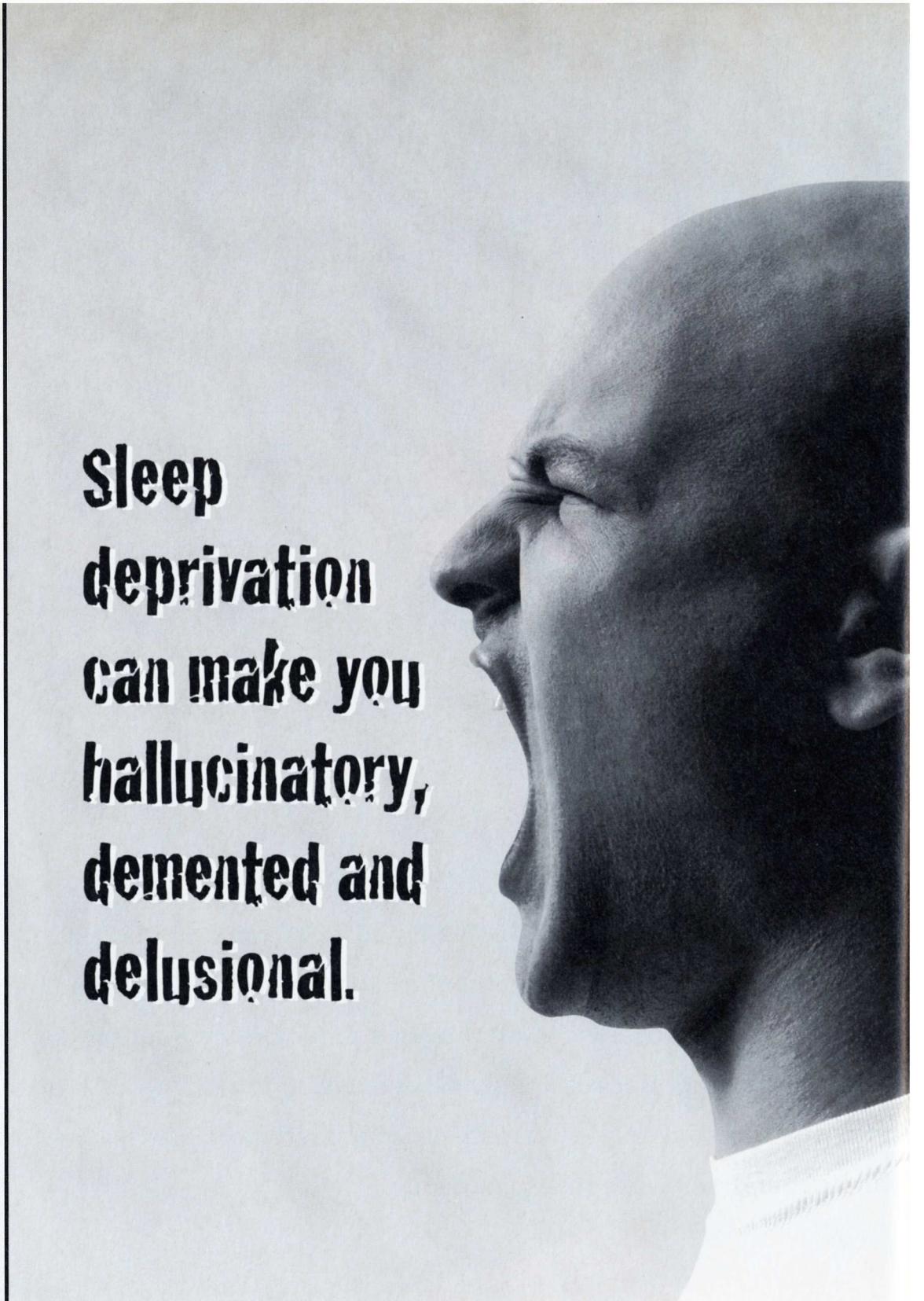
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G. PASCAL ZACHARY

Avoiding Annihilation

WILL THE WORLD ECONOMIC CRISIS LEAD TO A world innovation crisis? Let's hope not. Innovation spurs economic growth, but, more important, it raises living standards by delivering improved health care and new ways of satisfying human needs and desires. During the current economic crisis, innovation is especially important. Indeed, innovators are probably the only people who stand between a world in prosperity and a world in depression.

This is a big claim, but I think it's justified. The flow of innovation almost surely guarantees that the United States, and the world, will suffer no economic catastrophe. For out of new technologies come productivity gains and the opportunity to provide new goods and services. Innovation, in short, is the true source of wealth.

Hence, a puzzle: If innovation is so important, why do so many people take technological change for granted? Why is it seen as a given, as predetermined?

Innovators and their patrons need to make sure the global economic meltdown doesn't stifle technological change.



Consider the handwringing over the economic meltdown of Russia and the collapse of growth in Asia and parts of Latin America. Policy-makers and pundits have worried about a raft of dire possibilities: massive debt write-offs killing banks and drying up credit; tens of millions of people sinking into poverty; the breakdown of social order in many countries; and the spread of disease and ignorance as health-care systems and public schools deteriorate for lack of funds.

These are real concerns. Yet big thinkers have been curiously silent about what I see as an equally grave threat: that economic instability will stymie the world's innovators. So worried are investment bankers, politicians and CEOs about the specter of a global financial implosion that they've given nary a thought to the chance that a sustained downturn could hurt, or even halt, technological innovation.

One reason for this seeming indifference is that the best and the brightest have been spoiled by the torrent of innovations that has poured forth over the past two decades. As a result, they assume inventions and breakthroughs are produced automatically, regardless of business conditions.

Not so. To flourish, innovators depend on a healthy economy and a vibrant society. Whether engineers, scientists or inspired tinkerers, innovators are part of a societal ecology that shapes the nature of technological breakthroughs. Much as salmon thrive under the right river conditions, and disappear under the wrong ones, so the ranks of innovators wax or wane depending on the signals and support given by their environment.

What this means is that the current economic crisis could deal a body blow to innovation. Those who ignore their deteriorating environment do so at their peril. Here are five steps innovators and their patrons can take to avoid annihilation during what could be a prolonged global downturn:

■ *Think Big.* When business is booming, innovators are rewarded for small improvements in their products. Customers are eager to buy and have the money to spend on minor advances. That isn't the case during a downturn. It may seem smart, during a crisis, to grow more cautious, but the opposite strategy will reap bigger benefits. Throw off restraints and think big.

■ *Simplify Organizations.* During the 1990s research and development became a global proposition. The best companies opened engineering labs around the world, using networked computers to share information among far-flung teams. This approach worked well when companies were cash-rich; it is a liability in times of austerity. To stretch research dollars, simplify organizations.

■ *Break Bottlenecks.* It's been nearly 15 years since makers of semiconductors, computer systems and software have suffered a business slump. During this long boom, bad habits have proliferated. Consider software makers who have been accused of slowing innovation with clunky programs that consume too much computing power. Product cycles have so shortened, meanwhile, that customers can't adapt to the latest model before it is superseded. In flush times, many customers will take a chance on frustrating technologies. Not in a downturn.

■ *Get Help.* High-tech tycoons eschew government assistance except when they want to bash Microsoft. This animus toward government is a luxury high-tech innovators can't afford in a time of economic turbulence. Government and industry should hold a summit meeting to discuss how cooperation between the two might partly offset weaker business conditions.

■ *Stick Close to Home.* Foreign sales have carried U.S. high-tech companies to new heights. But the domestic market remains the world's biggest and the least expensive to reach. In the recent past it has been routine for even the tiniest new venture to open its doors simultaneously in the United States, Europe and Asia. With Asia in a slump and European business complicated by the arrival of the "euro" currency next January, it makes sense for American innovators to court the customers they know best. The United States isn't immune to an economic downturn, but it probably will suffer less than any other part of the world.

For U.S. innovators, that's the good news.

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Could an insurgent band of programmers, motivated not by profit but by the ideal of "free software," undermine Microsoft's control of the computer desktop?

Programs to the People

BY CHARLES C. MANN

PHOTOGRAPH BY ANN STATES

MIGUEL DE ICAZA SPENDS his days as a computer-network administrator at the Institute of Nuclear Sciences at the National Autonomous University of Mexico, in Mexico City. Watching over the network, he says, "gives me a lot of spare time"—time he spends answering e-mail and working on "fun little projects." His current spare-time computer activity, he thinks, is "really great." De Icaza is coordinating the GNOME project, a volunteer effort to develop a computer desktop—a mouse-and-windows interface—that will outdo the various incarnations of Windows that form the foundation of the Microsoft empire.

The GNOME desktop, its programmers say, will be faster, more powerful and less likely to crash than anything from Redmond, Wash. "It's a radical step forward in computer design," says Larry McVoy, a former Sun Microsystems programmer who now runs a networking startup in San Francisco called BitMover, "the coolest, whizziest thing out there." And GNOME will be free: downloadable from the Internet without charge.

The notion of a small band of unpaid part-timers challenging one of the world's most dominant corporations may seem absurd, but the GNOME project intends to do exactly that. "They have decided to take the desktop back from Microsoft," says Eric S. Raymond, a free-software evangelist who is editor of *The New Hacker's Dictionary*. In his view, there is a good chance that the project could succeed. "It's not at all impossible," Raymond says, "that GNOME could push the software world into a dramatically different—and better—place."



Big hack attack: GNOME coordinator Miguel de Icaza wants to give the computer world a choice.

Why would GNOME succeed where bigger, richer outfits—Apple, most prominently—failed? Two reasons, according to its backers. First, GNOME is not starting alone. It is designed to work with an operating system called Linux ("LINN-uks"). Renowned for its speed, reliability and efficiency, Linux runs on as many as 10 million computer systems around the world, ranging from small, geek-oriented networks at Internet-service providers and university computer labs to huge outfits like Wells Fargo and the U.S. Postal Service. With a user base growing at an estimated rate of 40 percent per year, Linux is the sole non-Microsoft operating system that is expanding its market share. *(See "Looking for Linux?" page 42.)*

Although more than 20 small companies now sell computers preloaded with Linux, the system is rarely found in homes because its reputation for technical excellence is matched by its reputation for user-unfriendliness. Indeed, one standard installation guide begins by admitting that Linux is "one of the most complex and utterly intimidating systems ever written," because users must type runic commands like "awk," "grep" and "mount -t iso9660/dev/cdrom/mnt." By providing a simple, intuitive point-and-click interface, "GNOME will make it possible for my wife, my mother and my grandfather to use Linux," says Michael Fulbright, a project member at Red Hat Advanced Development Laboratories, a corporate-sponsored Linux think tank in Research Triangle Park, N.C. "Finally, nongeeks will get to use something that geeks take for granted: software that works right." And once people see what it's like to use good software, Linux partisans argue, they will never go back to Windows.

The second, larger reason that GNOME could succeed is that, like Linux, it is a product of what is known as the "free-software" or "open-source" movement. Not only can GNOME be obtained free of charge, but its source code—the underlying instructions that most software firms regard as their crown jewels—will be available for anyone to copy and modify. By liberating the source code from the control of a single company, projects like GNOME can harness the contributions of thousands of programmers. Because not even giant Microsoft can surpass the united talent of the whole world, free-software partisans argue, open-source software will always outstrip the competition. "Produce something better and people will eventually notice," says Bruce Perens, a free-software programmer who works at Pixar Animation Studios in Richmond, Calif. "GNOME will be one ticket to the future."

Free-software projects like GNOME can harness the contributions of thousands of programmers.

In Mexico City, de Icaza describes the project in less grandiose terms. "GNOME will be fun," he says. "A really good hack."

Liberated Code

IF GNOME, LINUX AND THE FREE-software movement had a single beginning, it was the day in 1979 when Xerox donated one of the first laser printers to the Artificial Intelligence Laboratory at MIT. The machine crashed a lot, inducing AI Lab programmer Richard Stallman to ask Xerox for the code that controlled the printer. Stallman planned to modify the program to respond to breakdowns by flashing a warning on the screen of everyone who was waiting for a printout—that is, everyone who had an incentive to fix the printer right away. In this way, the printer would always be quickly set right.

To make this modification, though, Stallman needed Xerox to give him the source code for the printer program. For him, this was an unexceptional request. In the freewheeling academic atmosphere of the AI Lab, programmers worked communally, constantly borrowing and tinkering with one another's code. Moreover, Xerox had given Stallman the source code for an earlier, equally trouble-prone printer. This time, however, Xerox refused—the company had copyrighted the source code. Stallman was irate: Copyright was preventing him from improving a program. "Xerox was hoarding software," he says. "They were violating the Golden Rule."

Xerox was not alone. As software became big business, Silicon Valley lured away many of the AI Lab's best and brightest. When these programmers worked for software companies, Stallman discovered, their code was proprietary—it couldn't be shared and built upon. Copyright, the idealistic Stallman slowly concluded, was destroying the programming community.

In 1984, Stallman founded the Free Software Foundation. Its chief goal was to develop an improved operating system that looked like, but did not use the source code of, Unix—the most common operating system on big computer networks. Invented in 1969 by two researchers at Bell Labs, Unix is now available in a dozen different versions from companies like IBM, Compaq and Sun Microsystems. Stallman called his version GNU, a recursive acronym for "GNU's Not Unix." To avoid "horrible confusion," he pronounced it "guh-new." In a tip of the hat to Stallman, GNOME, which stands for GNU Network Object Model Environment, is pronounced "guh-nome."

The challenge of GNU was enormous. An operating system defines what services programs can ask of a computer (adding two numbers, moving information onto a hard disk, and so on) and directs requests for those services to the hardware (keyboard, monitor, microprocessors and so on). But the system is useless without hundreds of subsidiary programs to perform specific tasks such as managing windows and communicating with printers and other peripherals. To produce a functional system, the GNU project had to create all these programs. "It's like building a jet plane from scratch in your garage," says Perens. "People thought it was impossible. And it probably would have been, if anyone less extraordinarily talented than Richard was in charge."

Based at MIT, the GNU Project was Geek Heaven—dim lights, bright monitors, late hours, Chinese takeout. At the center was the bearded, long-haired Stallman, pounding code late into the night and sleeping during the day on a cot in the offices. Every line he wrote was "copylefted"—users could freely change the

software, as long as they didn't prohibit others from doing the same to their modifications. "Copyleft," Stallman says, "uses the tools of the software hoarders against them."

By the early 1990s, though, the GNU project was foundering. It had created scores of programs that were used all over the world—but had not produced the heart, or "kernel," of the GNU operating system. Part of the reason was that Stallman had chosen not to duplicate the tried and true Unix kernel but to base the GNU system on an advanced, experimental kernel developed at Carnegie Mellon University. The only programmer ever to receive a MacArthur "genius" fellowship, Stallman was one of the few people in the world up to the task of developing a radically new kernel—and possibly the only one who could think of doing it almost single-handedly.

But then his hands, weary from typing so much code, gave out. For years pain prevented him from serious work at a keyboard, and his work on the kernel stopped. Stallman tried to continue by employing MIT students as transcribers. Recalls Perens: "He would treat them literally as typewriters, saying 'carriage return' and 'space' and 'tab,' while he dictated what he saw in his head." Invariably these human typewriters quit after a short time, worn down by hours of robotically transmitting computer code.

Nobody stepped in to replace the sidelined Stallman. One reason, says Perens, was political. "Richard is the last of the pinkos. And people just didn't want to be associated with somebody whose ideas are fundamentally antagonistic to business."

The Little Operating System That Could

ENTER LINUS TORVALDS. A 21-YEAR-OLD undergraduate at the University of Helsinki in 1991, Torvalds was far from an expert programmer—"I didn't even know what I didn't know," he says. But he knew Unix well enough to regard Microsoft's MS-DOS operating system as a mess—the digital equivalent of being forced to write with a leaky pen. Still, Torvalds wanted to program, and he got so sick of the long lines at the campus computer center that he bought a PC. The machine—a 386 with 4 megabytes of memory—was too small to run Unix. But he still refused to subject himself to bad software. Ignoring DOS, Torvalds mashed together chunks of code from his instructors' and his own work.

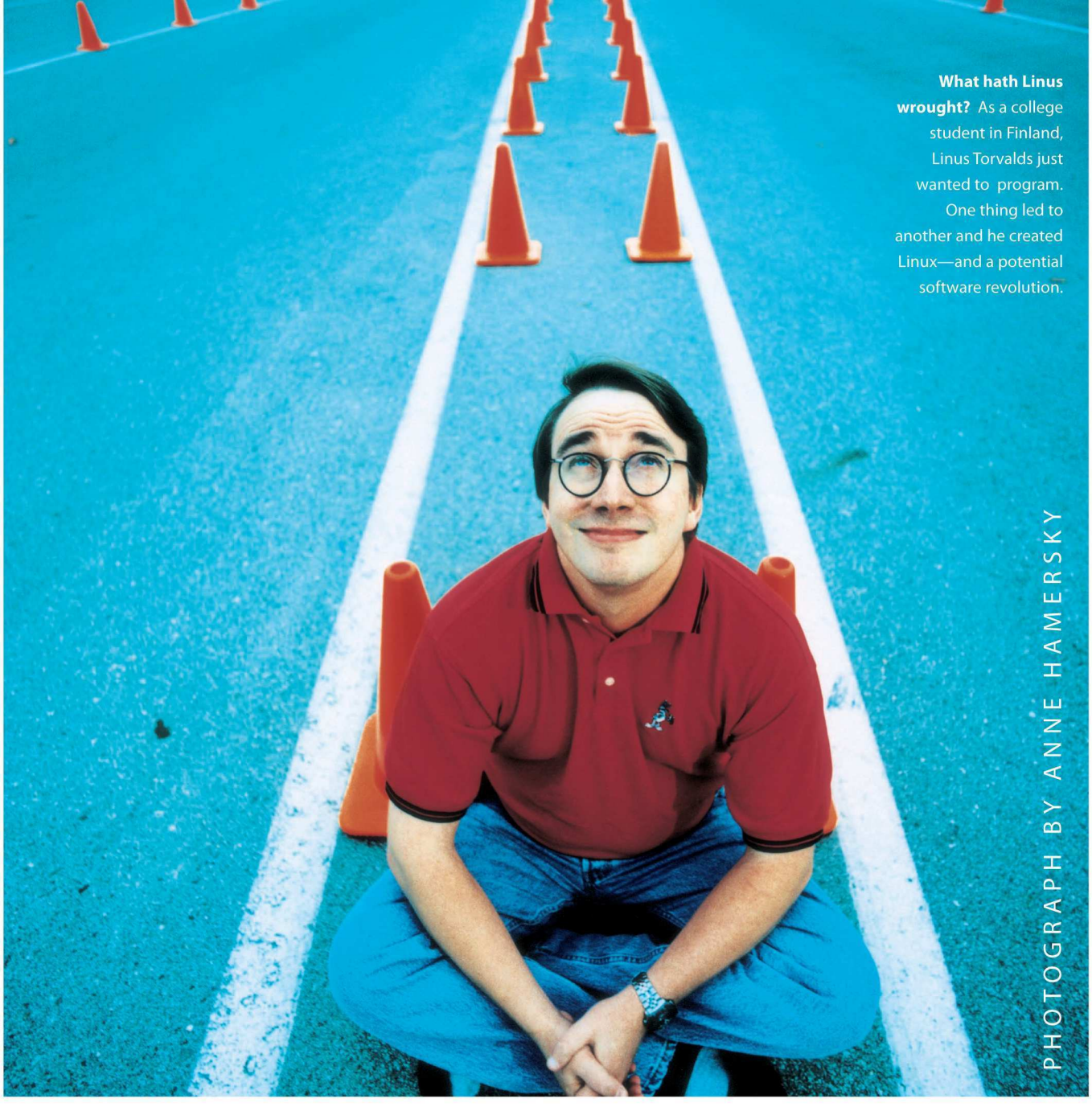
Somewhat unexpectedly, Torvalds ended up with something like a Unix kernel. Because the GNU project had created the necessary subsidiary programs, he tweaked the kernel to fit them. Lo and behold, he had backed himself into creating a complete operating system. For the first time, the flexibility, stability and power of Unix were available on a small computer. Torvalds called his operating system "Freax." His friends thought the name was dumb and changed it to Linux.

On a personal level, Stallman and Torvalds are opposites. Stallman is a provocateur with cheerfully irregular habits—a nocturnal bachelor who bites off the split ends in his long hair as he proposes the idea of a national campaign to mock Bill Gates. Torvalds is polite, softspoken and personally tidy—a married man with a regular job. But the pair share one important attitude: antipathy to software copyright. Torvalds covered Linux with Stall-



PHOTOGRAPH BY FURNALD/GRAY

Godfather of GNU: MIT's Richard Stallman wanted to fix a printer. He wound up starting a crusade.



What hath Linus wrought? As a college student in Finland, Linus Torvalds just wanted to program. One thing led to another and he created Linux—and a potential software revolution.

PHOTOGRAPH BY ANNE HAMERSKY

man's "copyleft" and posted it online for anyone to download; when people added improvements, he put them, too, on the Net. Begun in 1991 as an Intel-only operating system with a single user (Torvalds), Linux had been modified by 1995 to run on machines from Digital and Hewlett-Packard and had half a million users, many in developing nations.

"Everything came together at the right time," says John Hall, a Linux maven who is a technical marketing manager for Compaq. "The price of PCs dropped and their power went up, so people in poor countries could maybe afford 486s and 386s that were halfway serious computers." This new wave of geeks wanted to try their hands at cutting-edge computer science. With few outlets in the developing world for their talents, they seized on the opportunity to participate in the development of Linux through the Internet. "Suddenly," Hall says, "there was the possibility that not all of computer science would come out of Redmond, Washington."

The story of GNOME project leader Miguel de Icaza illustrates the point. Discovering the GNU project at the age of 18 in 1991 as an undergraduate at the National Autonomous University of Mexico, de Icaza quickly began working on its file manager program. "I wanted to give them something back because the software was so good," he says. Soon came Linux, which he coupled with GNU software and adapted to the Sun SPARC workstation. "Once I started contributing," de Icaza recalls, "people started sending me improvements and bug fixes and new features." No one cared that de Icaza wasn't American or that he hadn't finished college. (No one, that is, except the U.S. government, which refused him a working visa when Cobalt Networks, a Mountain View, Calif., computer company, tried to hire him.)

Hundreds of programmers like de Icaza worked on Linux, adding utilities, fixing bugs, writing manuals, adding capabilities and porting it to different computer systems. New versions poured out at an astonishing rate—sometimes more than one a week. Each would be downloaded and worked on by people around the globe. Overwhelmed by the runaway project, Torvalds restricted himself to supervising the kernel. People interested in working on other pieces organized themselves, Andy-

Hardy style: *Hey, kids, let's make it page to disk!* In the end, Torvalds says, "less than five percent" of the code is his. (He now works for Transmeta, an ultrasecretive Silicon Valley chip-design company. What is Transmeta? "We do stuff," Torvalds says, deadpan. "That is the official company line.")

To free-software advocate Raymond, the novel development of Linux presaged a sea change in software. In a widely read essay, "The Cathedral and the Bazaar," he argued that software before Linux always had been produced in a "cathedral," by an isolated team of programmers, who worked on the code until releasing a final, finished version. Linux, on the other hand, was assembled in a "bazaar," by a cacophonous scatter of independent programmers. And Linux was never finished. Ordinary users work with particularly successful "snapshots" of the operating system, but programmers keep fiddling with it as long as they see something to add or fix. (Raymond has put the essay on the Web, at http://sagan.earthspace.net/~esr/writings/cathedral-bazaar/.)

Writing software in a bazaar is easier, more efficient and more likely to be successful, Raymond believes. Because the source code is open to all, he says, "we very seldom have to solve the same problem twice." Commercial software developers, by contrast, are often forced to reinvent the wheel—"an almost criminal waste of resources." When one company invents a way to e-mail data from a program directly, for example, competitors can't build on the work and improve it. Instead they must start from scratch and figure out a completely different way to do the same thing. The result, open-source devotees argue, is not healthy competition that produces incremental improvements, but a set of incompatible products that don't work very well.

In addition, open-source software can be tested more thoroughly. Even big companies typically field-test their operating systems only with a few dozen users, according to Compaq marketing manager Hall, who worked on operating systems for Digital—a far cry from the thousands who put each Linux version through the wringer.

Moreover, as Torvalds has argued, open-source programmers don't have to worry that "fixing one bug might just break a hundred programs that depend on that bug." If Microsoft changes Windows 98, it can't easily peek into the source code of Quicken or WordPerfect to see what will happen; nor can independent hackers readily post a correction. By contrast, bugs in free programs can be avoided or fixed quickly, because the source code is available to all. In a test of software reliability published last May, seven computer scientists at the University of Wisconsin concluded, to their surprise, that GNU and Linux programs were "noticeably better" than their proprietary equivalents.

Open-source boosters say that Linux/GNU has advantages for users, too—and especially businesses. Instead of being forced to accept the features that big vendors like Microsoft choose to make available, corporate information-systems departments can create software that exactly fits their companies' needs. Partly because of its easy customizability, free software is spreading into the business world (although some companies remain leery enough of the idea that systems administrators conceal it from management). Sega uses Linux to develop video games; Digital Domain, the James Cameron company, used it to produce digital special effects for *Titanic*. The U.S. Postal Service routes letters with RAF Mail character-recognition software, a commercial program that runs on Linux. Netscape and Intel announced in September that they were investing in Red Hat, the largest commercial Linux distributor.

But Linux has been almost shut out of one large arena: the consumer market. As long as it remains triumphantly nonintuitive—"a program for hackers by a hacker," as Torvalds puts it—its use would be confined to geeks. Which, to some Linux partisans, was not enough.

World Domination?

THE OBVIOUS WAY TO POPULARIZE LINUX is to give it a point-and-click desktop akin to that of the Macintosh and Windows. Such a move, however, was of little interest to the type of person who developed Linux. Most programmers like typing on a command line because it lets them control the machine more precisely than they can by clicking on a mouse.

Torvalds himself says he doesn't care much about "nice graphical interfaces." Indeed, at first he wasn't sure that Linux would function well with one. But Torvalds ultimately welcomed Miguel de Icaza's announcement in August 1997 of the GNOME project: an attempt to put together a graphical user interface. "I joke a lot about Linux taking over the world and how Microsoft should be afraid," says Torvalds, who has recently conducted "World Domination 101" seminars at Linux conventions. "But with something that makes it easy for the home user—maybe it just might happen."

Proponents of GNOME faced several obstacles. First, a Linux desktop project already existed. Based in Germany and called the K Desktop Environment (KDE), it was under heavy attack within the open-source community. In a perfect example of the arcane squabbling endemic to passionately idealistic enterprises, the open-source community battled over whether the KDE

Goliath Gets Nervous

Any questions about whether Microsoft regarded open-source software (OSS) as a potential menace were laid to rest in November, when two leaked company memos appeared on the Net. "OSS poses a direct, short-term revenue and platform threat to Microsoft," wrote company engineer Vinod Valloppillil in one memo. "The ability of the OSS process to collect and harness the collective IQ of thousands of individuals across the Internet is simply amazing."

Software of "commercial quality can be achieved/exceeded by OSS projects," Valloppillil admitted. To support this argument, Valloppillil and Josh Cohen, another Microsoft developer, compared the performance of Microsoft's Windows NT and Internet Explorer with two open-source products, Linux and Netscape Navigator, on the same computer. Their conclusion: "The combination of Linux/Navigator ran at least 30 percent to 40 percent faster when rendering simple HTML [the text and commands on Web pages] plus graphics."

The second memo concludes that "Linux's hacker orientation will never provide the ease-of-use requirements of the average desktop user." But the GNOME project could change all that—which is one reason it's attracting increasing scrutiny from Redmond.

Looking for Linux?

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Caldera Systems	1-888-GOLINUX www.caldera.com	$59; 30 days of phone/e-mail support.	Second in commercial Linux market. Includes KDE, rival desktop to GNOME.
S.u.S.E.	1-888-UR-LINUX www.suse.com	$49.95 ($79.95 for package with KDE and office suite); 60 days of free phone/e-mail support.	German Linux leader, with U.S. offices in Silicon Valley.
Debian	www.debian.org	Free download. No direct support, though Linux e-mail lists are famously helpful.	Branch of Software in the Public Interest, a nonprofit corporation that supports GNOME.

INFORMATION

Linux Online	www.linux.org	Semi-official site promoting Linux—often swamped.
Linux Center	www.linux-center.org/en/	A Yahoo-like index to Linux based in France.
The GNOME project	www.gnome.org	Comprehensive site for users and software developers.
Free Software Foundation	www.fsf.org	Headquarters of Stallman's GNU project.

desktop was fatally tainted because it included code from a Norwegian company, Troll Technology, that was not completely nonproprietary. The short answer is: probably. Which was one reason de Icaza, and then much of the Linux community, shifted attention to GNOME.

Within a year of the project's inception, more than 150 people were developing GNOME, about 20 of them full-time. Red Hat hired seven full-time programmers to work on it. This crew is, of course, infinitesimal compared to the battalions of programmers laboring to produce each new version of Windows. On the other hand, "we don't have to go through the contortions they do," says Todd Graham Lewis, keeper of the frequently-asked-question file for GNOME. "One hour of work on Windows 98 means 15 minutes of working on functionality, and 45 minutes of checking on DOS compatibility, Windows 3.1 compatibility, and Windows 95 compatibility. One hour of work on GNOME is one hour of functionality." Partly for this reason, the project has moved quickly; version 1.0 may be available at www.gnome.org as early as the beginning of 1999.

Describing the result isn't easy, because the project is creating a desktop that users can configure themselves—in other words, one with no standard appearance. "Windows has a set of colors and fonts you can change," says Carsten Haitzler, a GNOME programmer at Red Hat. "But that's all you can do. We want you to be able to customize everything from the ground up."

Users who don't want to tinker with the desktop can choose among scores of pre-fab "themes"—although most of the current themes, which have been produced by young male programmers, resemble the covers of science-fiction novels. "People say my desktop looks like something out of *Babylon 5*," Haitzler says proudly.

The GNOME project aims to emulate what is best about existing interfaces. "Microsoft did some things very well, and we're trying to learn from them," de Icaza says. At the same time, the project seeks to avoid some of Windows' annoying design peculiarities. GNOME users, de Icaza promises flatly, will not turn off their computers by clicking a button labeled "Start." Nor will they have to struggle with the Windows taskbar. To bring a program up on the screen, Windows users click once on a taskbar button but, confusingly, must usually click twice on a tray icon.

GNOME, de Icaza says, will deliver a more logical interface. Instead of scattering icons around the desktop, where they are covered up by windows, users can drag documents onto the "panel"—the GNOME version of the task bar. Multiple panels can be kept open in different places on the screen. Because the panels can change appearance—one Doom-influenced theme has a panel made from a line of skulls with icons in their yawning mouths—GNOME, McVoy says, is "serious eye candy."

Eye candy won't be enough to attract the novices if they can't do anything, though. One of Linux's most serious weaknesses is the relative paucity of business and home software available to run with the operating system. Few office-suite and game companies offer products that run under Linux. Two exceptions are id Software, which has Linux versions of the popular games Quake and Doom, and Corel, which has come out with WordPerfect for Linux and has promised to create Linux versions of the rest of its office suite. To make up the gap, both GNOME and KDE have launched free-software projects to create word processors and spreadsheets; early test versions are expected in the spring.

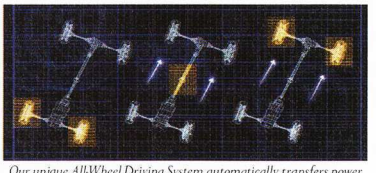
Microsoft, watching closely, is already proposing measures to counter Linux *(see "Goliath Gets Nervous," page 41)*. But Lewis points out that open-source software has one undeniable competitive edge. "Microsoft kills its rivals by starving them of revenue," he says. "But they can't kill us that way, becuse we don't have any revenue. The free software movement is like *Night of the Living Dead*—we'll keep coming at them."

Adds Raymond: "There's a Gandhi quote Linux hackers love: 'First they ignore you. Then they laugh at you. Then they fight you. Then you win.'" ◊

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A company notorious for purchasing other people's inventions has decided to cook up its own ideas. But Microsoft Research is struggling to escape a reputation as an irrelevant playpen.

Software's Ultimate Sandbox

BY ROBERT BUDERI

BUILDING 9 DID NOT LOOK happy. It was another drizzly October day on the rain-drenched Microsoft campus in Redmond, Washington—and the mood outside only augmented the tempest within. Offices were being cleaned out, desks and file cabinets either missing or abandoned, boxes of equipment stacked in the halls. Many inhabitants of the sleek two-story structure had opted to work at home in the face of a triple horror: no computers, no e-mail, no Internet.

Moving day for Microsoft Research. The lab was deserting its headquarters in the center of the Soft's big quad for Building 31, a roomier three-story facility on the northeast end of the action. Upheavals are common at the titan of software—but the ride Research has taken counts as wild even by Microsoft standards.

Since its 1991 inception, this foray into the future has gone full-out to woo the best and brightest computer wizards. The lab has grown rapidly, overrunning its headquarters and sprouting offshoots in San Francisco, Cambridge, England, and, as of last November, Beijing. While their names might not ring bells in Peoria, a swarm of digital legends now pad Building 31's carpeted halls, among them laser printer inventor Gary Starkweather, personal computer pioneer Butler Lampson,

KAREN MOSKOWITZ/OUTLINE



Dreamer in Chief: Theoretical physicist Nathan Myhrvold wrote a research manifesto that appealed to Bill Gates' paranoia.

multimedia oracle Linda Stone, and graphics gurus James Kajiya and Alvy Ray Smith. Microsoft's digerati are busy shaping a future of startling 3-D images, machines that talk and respond to a person's expressions, and lifelike Web-roaming agents. Among corporations, perhaps only IBM and Lucent Technologies boast larger computer science efforts, and the lab rivals programs at top universities such as Carnegie Mellon and MIT.

Seven-plus years into the lab's existence, though, it's getting to be put-up time. While researchers have placed code in a wide range of products, the lab has fallen short of its stated aim of providing true breakthroughs. And without real eye-opening advances to its credit, Microsoft Research has yet to answer the question on the minds of many computer industry watchers: Can a giant assailed for its lack of innovation—whose cornerstone products such as DOS, Windows and Internet Explorer spring largely from purchased technology—find a way to innovate from within?

Only the Paranoid Survive

NOT SURPRISINGLY, MICROSOFT'S RESEARCH managers answer "Yes." With the goal of uniquely blending the free-thinking of academia with the business mantra of shipping products, the brain trust in Redmond believe they're on track to follow in the footsteps of General Electric, AT&T, IBM and other major corporations that used their dominance to build precedent-shattering research labs. That may well be. But the upstart venture has not yet earned the full respect of industry watchers and rival organizations. The word is that Microsoft's expanding galaxy of computer science stars still has a lot to learn about innovation before taking center stage in shaping the future of personal computing.

Late last year, building 31 might have stood as a metaphor for Microsoft's research enterprise: ambiguous and unfinished. The lab's new home has the same cream-colored exterior with bluish-green trim as most Soft edifices. But its two parallel wings, joined by a boxlike center section that harbors an impressive atrium, give it a more high-tech corporate sheen than its lower-key counterparts. Inside, nearly all the offices look out on lush greenery.

The whole Microsoft research enterprise started with polymath Nathan Myhrvold, now the company's chief technology officer. Four years after graduating from UCLA at 19, Myhrvold earned a doctorate in mathematical and theoretical physics from Princeton; he then won a fellowship under Stephen Hawking at Cambridge University, where he studied quantum field theory in curved space-time. More recently, the 39-year-old Myhrvold has dabbled in mountain climbing and formula car racing. He even makes sporadic appearances as an assistant chef at Rovers, one of Seattle's



Ivory tower talent: Computer networking expert Rick Rashid left Carnegie Mellon to join Myhrvold's embryonic lab. Now he's research vice president.

PHOTOGRAPHS BY REX RYSTEDT

best French restaurants.

Myhrvold hooked up with Microsoft chairman Bill Gates in 1986, when Microsoft purchased Dynamical Systems, a Berkeley software company the mathematician had founded. Five years later, as head of advanced development, Myhrvold proposed creating a research laboratory to help Microsoft take charge of its future. His "vision statement" argued that the best way to ensure continuing access to strategic technologies was "to do it yourself." That idea appealed to Gates' paranoia. Even as his company grew dominant—ultimately provoking antitrust investigations that led to the company's trial last fall in federal court—the software kingpin still worried about garage inventors killing his business with an unforeseen innovation. So in July 1991, Microsoft announced a new commitment to longer-term research.

The move hardly brought it into the ranks of the great industrial research organizations such as Bell Labs or IBM. Still, the creation of Microsoft Research marked a first for the software industry, which had always concentrated on developing its next product generation. By establishing the lab, Microsoft signaled its intent to be a player in such fields as speech recognition, futuristic user interfaces and 3-D graphics—cutting-edge technologies that might not bear fruit for years.

To build the lab, Myhrvold brought in Rick Rashid, a computer networking expert from Carnegie Mellon. Rashid, in turn, landed Dan Ling, a rising star at IBM; Ling, Rashid's undergraduate roommate at Stanford, had co-invented the video-RAM and led research in everything from workstation architecture to data visualization. The lab gained momentum steadily, and around 1996, things really took off. Two-thirds of the current staff have worked at Microsoft Research less than two years—and with Rashid risen to research vice president, new director Ling (*see "Listening to Ling," page 49)* has a mandate to double the lab's current 300-person payroll by the millennium.

Even a 600-person operation only represents a small gamble. Microsoft's fiscal 1999 R&D budget should hit $3 billion, the vast majority dedicated to upgrades of existing products and services. Therefore, spending a fraction (a good guess is $100 million, though officials won't say) on blue-sky research seems reasonable.

And the potential payoff is immense. Like many corporate and university labs, Microsoft wants to move into the age of ubiquitous computing, where networked brains permeate everything from coffeemakers to TVs. Joined by everyone from Big Blue to Intel and a host of startups, it also seeks to create a rich, Web-based communications medium, where PCs respond to gestures and eye movements and rapidly redraw screen images to depict where people are pointing or looking. Microsoft may have entered the field late, but the market is still up for grabs—and Gates, Myhrvold and company have wielded their clout and cash to assemble a lab that's up to speed on the software and graphics technology that sets personal computing standards in the 21st century.

Achieving such human-machine symbiosis will likely take decades. So why should Microsoft support PhD linguists when it could just wait and buy out whatever hacker solves the problem? Well, aside from the fact the solution might involve a novel operating system that renders Windows obsolete, the plan is to use what's learned along the way to improve a slew of applications.

Enter the NLP Product Rainbow, a graphic that lays out milestones Vanderwende and colleagues hope to achieve. The "rainbow's" inner arc depicts scientific goals—word breaking, morphology, syntactic sketch, logical form, discourse and meaning representation. The outer arc lists products the group expects to spin off as it reaches the scientific goals: grammar and style checker, information-retrieval applications and programs that scan and summarize documents.

The group hit the morphology, word breaking and syntactic sketch milestones about two years ago. The achievement involved creating a simplified dictionary that contained most words in the English language, then writing codes that enabled the computer to parse any sentence. This brought researchers closer to the goal of meaning representation. But Vanderwende and her NLP research colleagues also saw in their creation the foundation for a commercial product—a grammar and style checker better than the one Microsoft licensed from Inso, formerly a Houghton Mifflin division.

The team built a program designed to outperform Inso's product, adding such features as the ability to change passive sentences to active. After product development counterparts conducted tests that confirmed the new program's superiority—and pointed to further improvements—Microsoft dropped the Inso contract and installed its home-grown checker in Word 97. With that one move, notes research director Ling, Microsoft got far more than an improved product and some extra cash. "Built into every copy of Word now is a program that can parse English sentences

Microsoft Research marked a first for the software industry, which had previously focused mainly on products.

The Product Rainbow

THAT'S A TALL, BROAD ORDER. BUT MICROsoft has set its priorities clearly. Among its prime goals: develop technologies that give people the ability to interact with computers using normal, everyday language. Leading the effort to capture this Holy Grail of computing is the natural language processing (NLP) group, whose 20 members make it one of the lab's largest efforts. NLP aims to enable computers to grasp the meaning of any text—typed, e-mail, or voice converted to text—and then take action based on that understanding.

"If you can do that, you can get the feeling that the computer is behaving intelligently," says NLP theoretical linguist Lucy Vanderwende, a friendly woman who radiates love for her work. Still, it's a gnarly problem that involves knowing grammar, style, semantics, word morphology and even context. Only then can computers understand the myriad ways of saying the same thing and make sense of ambiguous utterances, such as: "I ate the fish with bones." Such a statement wouldn't faze a human, but a computer might think that you wield bones like a fork to eat the fish. Going a step further, suppose you'd forgotten a file name but could simply tell your computer: "Find that note I took a few weeks ago after Bill G. called"?

of substantial complexity and length," he says. "It is the foundation for building lots of different natural language tools."

That's already happening. Recently, NLP researchers created Mindnet, a vast information repository automatically built from the contents of two dictionaries by analyzing their text with the same parser that lies at the heart of the grammar checker. The first-of-a-kind system can be accessed while the parser dissects grammar and logical form, enabling it to forge links between words with similar meanings. This gives computers the smarts to treat "I saw the hatchet" and "The ax was seen by me" as two ways of saying essentially the same thing. Such flexibility in vocabulary, and even sentence construction and grammar, marks a big step toward allowing people to communicate with computers more naturally.

Related technology opened the door for an improved search-and-retrieval program incorporated into Encarta 99, an updated version of Microsoft's CD-ROM encyclopedia, due out this Christmas. In addition to scanning the table of contents or launching key word searches, Encarta users can find information by entering a natural language query, such as: "What animals eat insects?" The system doesn't provide answers—yet—but points up likely articles that Vanderwende says often wouldn't have been found with more traditional searches.

Such a capability—at least in name—has already appeared on big search engines such as Alta Vista. But these are essentially key-word search engines. That means if you ask: "How many hearts does an octopus have?" you'll be referred first to articles that mention both heart and octopus, followed by those with one of those two words—and, in some cases, thousands of citations for articles with the word "how." By parsing the query and doing further processing of the logical form, the Microsoft product avoids this trap. Explains Vanderwende, the logical form says that "octopus" is the subject of the act of having and "hearts" the object.

The new tool also parses the entire text of Encarta—then looks for full or partial matches between the logical form of the query and the logical form of any sentence in the encyclopedia. In most cases, she says, users will get back a listing of all the articles in Encarta related to the query. But even if some are missed, she guarantees one thing: "We don't bring back a lot of crud."

Flowing Along

NATURAL LANGUAGE PROCESSING IS PART of Microsoft's overall goal of making computers—well, more like people. Machines of the future should be able to respond not only to spoken commands but to gestures and facial expressions. Indeed, it's by fusing advances from a variety of research areas that managers expect to realize the full potential of their interdisciplinary lab. That hope is embodied in "flow."

The idea is that computing is undergoing a fundamental transformation. Having started out as a behemoth calculator, then evolving into an office productivity tool, argues Jim Kajiya, the computer is now becoming "primarily a medium for information flow." The signs are in the ether: e-mail, computer-driven videoconferencing, Web surfing—these things go beyond document preparation to communication and learning about the world.

At Microsoft Research, two fields—vision and graphics—are converging rapidly to address the concept of flow. The basic idea behind the vision part of the challenge is to give computers the power to interpret and extract information from visual cues such as stored images or live camera feeds. Roughly half of Microsoft's 14-member vision group is working mainly on constructing fresh viewpoints of a given scene from just a few images of the setting, as shot from different angles. The other half focuses on vision-based user interfaces. This involves such problems as watching for faces through a camera mounted atop the computer and determining whether there's someone in front of the machine, where he or she is looking—even the expression on his or her face.

Graphics, of course, is heavily involved in techniques for assembling 3-D pictures. Senior graphics researcher Brian Guenter, for instance, is building an elaborate database of faces, facial muscle movements and expressions. When combined with speech recognition, natural language processing and vision technology, he hopes this archive will enable him to create virtual characters who communicate online via the spoken word—not text—and whose lips and expressions move in perfect sync with their voices.

Vision and graphics technologies might be combined like this: Users select a face as their online persona. They then sit at their computers, speaking into a microphone while a camera captures their expressions. Words, grimaces and smiles would all be broken into bits, transmitted over phone lines, and reconstructed in the virtual environment so that they appeared to emanate from the onscreen character. Such technology, Guenter believes, will prove a boon to online chat sessions and game-playing, where people want a degree of anonymity but desire more nuanced interactions than plain text affords.

The potential extends beyond the domain of online chat and game-playing. Kajiya, an Asian-American whose flowing mane and huge muttonchop sideburns make him look like a sci-fi zen master, also speaks of video-voice connections that will bring long distance, person-to-person communications into an entirely new dimension. The system would use programs that track gestures and eye movements and instantly redraw the screen image so that the person on the other end gets a different representation of the same scene, taking into account where his colleague is pointing or looking—just as they would in real life.

"Microsoft is not PARC"

SUCH PROJECTS IMPRESS AND EVEN CHARM. Even while pursuing its lofty dreams, however, the lab cannot escape comparisons to the one computer-science venture that got started with a similar blitz: Xerox's Palo Alto Research Center, or PARC. Formed in 1970, Xerox PARC took only a few years to fashion the graphical interface, laser printer and other core technologies that have come to define personal computing.

But there's a legendary catch. PARC was isolated from Xerox's East Coast headquarters, where copier-oriented suits didn't grok computing. The computer jockeys themselves lacked a sense of which technologies might actually sell—and in what form. They envisioned a $20,000 networked machine, the Xerox Star. It wasn't until Apple's Steve Jobs usurped their ideas for the Macintosh that PARC's inventions took off.

Is Microsoft destined to make similar mistakes? Given the huge customer base locked into its existing products, would

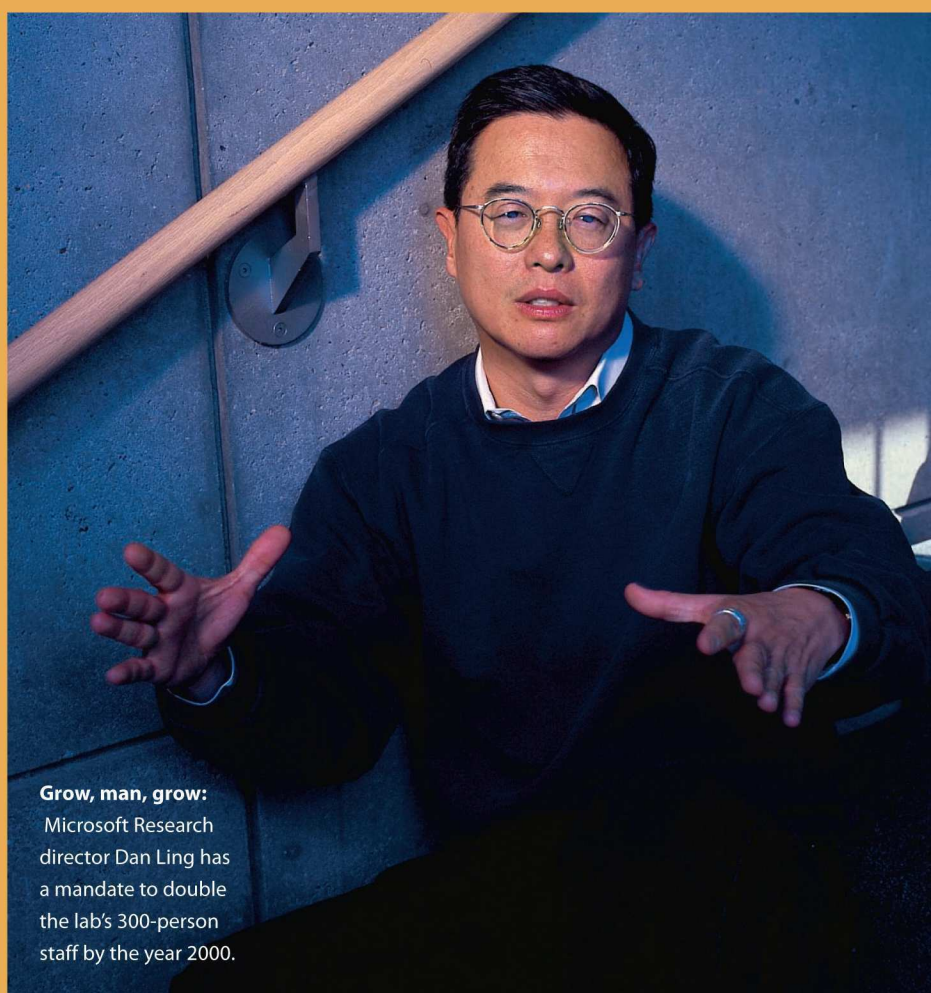
something truly revolutionary stand a chance of being embraced by Microsoft's business groups? Some observers say no—at least not without the company's experiencing the competitive hardships that rocked other labs in the early 1990s and forced researchers to work hand-in-hand with developers, marketers and customers to turn lab inventions into meaningful products. "I wonder if you can learn without going through the trials by fire," says one top IBM research manager, adding that right now, anyway, "my impression is that Microsoft Research is much more like a sandbox for playing."

There *is* a sandboxy aspect to the lab, almost as if its members are still simulating a great research effort before figuring out how to really do it. Computer industry research labs are famously casual—sports shirts and blue jeans. But Microsoft goes them one better: shorts and T-shirts. Rashid is a die-hard Star Trek fan who keeps a picture of himself with James "Scotty" Doohan on his office wall. Staffers hang with sci-fi writers such as Neal (*Snow Crash*) Stephenson and Greg Bear, who even created a character named Nathan Rashid in his book *Slant*.

And then there's Myhrvold, who reportedly netted $104 million from stock options sales in 1997 and was recently featured in an aircraft ad because he was the 100th person to order a Gulfstream V jet. In *Barbarians Led by Bill Gates*, former Microsoft developer Marlin Eller and co-author Jennifer Edstrom complain that the fast-talking visionary throws out ideas without understanding the challenges involved. In particular, they cite his misplaced early 1990s evangelism for interactive TV, which has gone into hiding at Microsoft and just about everywhere else. "Talking to Myhrvold was a little like smoking dope," they wrote. "It could give

Listening to Ling

Research Director and computer scientist Dan Ling joined Microsoft in 1992 after five years at IBM Research. TR *asked for his views on the future of computing—and his organization:*



Grow, man, grow: Microsoft Research director Dan Ling has a mandate to double the lab's 300-person staff by the year 2000.

ON TOMORROW'S PCS

We're interested in how we can make it more natural for humans to interact with computers—particularly through speech. Another goal is for the computer to be more aware of you and its surroundings. It should be able to see you, identify you, maybe even tell whether you're happy or sad, and then respond to those things. This will require fundamental technological breakthroughs.

ON HUMANS AND TECHNOLOGY

There is a cycle in technology. First you enable something to happen. Then there are consequences, which you try to control by using other technology. Take transportation, for example: We built cars and then we built the roads, and now we have traffic jams. But while technology keeps changing, the capabilities of an individual human remain roughly constant. And so managing human attention is becoming a critical concern.

ON THE INFORMATION TSUNAMI

People expect you to be able to respond quickly to a message, no matter where you are. People need techniques to help them manage that flow of information—whether that be visualization techniques, or agents of some kind that can filter information.

ON WHERE MICROSOFT NEEDS TO DO MORE RESEARCH

The amount of time and effort that goes into testing software, and getting the bugs out, is enormous. And yet there are still bugs, and people still complain and say nasty things. We're trying to think about breakthroughs that we can make to dramatically improve the quality of software.

ON MICROSOFT'S REPUTATION AS A TECHNOLOGY COPIER

That's very distressing, because we've done a lot of things that are very innovative. We are the only software company with a corporate commitment to doing research—I think that's very significant.



Guru of graphics: James Kajiya sees a fundamental transformation as computers become devices for "information flow."

you 'insights' but in the light of day those insights often didn't make any sense."

A more palpable portent of trouble may lie in the World Wide Web. It wasn't until December 1995 that Gates proclaimed "a second PC revolution—the Internet." To astute observers, being that late in the game was a symptom of big problems in the way research works at Microsoft. "They already have manifested to me a problem that we had been criticized for in the early days of PARC," says John Seely Brown, the innovation guru who now directs the Xerox lab. "How is it conceivable," he wonders, "that Gates did not understand the Internet until he did?"

Brown says that the evidence from Microsoft points in a disturbing direction: "Take the hypothesis that they have great researchers—and they've had them for some time." These researchers, observes Brown, certainly grasped the Internet's importance. Microsoft's apparent lack of alertness, he concludes, suggests that mold-breaking ideas must be funneled through Myhrvold and Gates before they can diffuse out to the ranks. Such funnels, he says, slow the spread of research ideas and curtail innovation. His admonition: "Watch out for funnels."

Arriving late at the Internet party may have been Microsoft's most conspicuous miscue, but it isn't the only one. Another ominous warning sign might be seen in Talisman, a system for rendering high-quality PC graphics. Microsoft touted it as a new standard. But Talisman proved to be a bust when it rolled out in late 1997. A big reason: the novel technology required software companies and graphics chip makers to adopt new procedures. Admits Kajiya, Talisman's chief architect and now the lab's assistant director, "It was just not natural for the market to do that."

Despite such misfires, however, competitors should not easily dismiss Microsoft's research arm. While Myhrvold has admitted attaching too little importance to the Internet in the early 1990s, Microsoft Research officials insist that the company was able to catch up rapidly because technologies developed in the lab were close at hand.

That may be viewing the experience through rose-colored glasses. Still, it's hard to find a major company that wasn't behind the Internet curve, albeit not as far as Microsoft. And no good lab can escape at least a few Talisman-like disappointments: If it doesn't have some flops, it's not thinking big enough. Besides, Microsoft's research brain trust is keenly aware that what's far more important than isolated successes and failures is a lab's connection to the rest of its company—and its business objectives. They claim Microsoft's research venture is well protected against becoming a software ivory tower.

Indeed, Microsoft deliberately established the lab on the main corporate campus rather than near an academic center à la Xerox PARC. The goal: Keep business objectives high in researchers' minds. Staffers routinely lunch with product group colleagues, and when technology is transferred, researchers often join developers in the business units until products are complete. Those close ties help ensure that the lab tackles problems important to the product side—and that product personnel know what research can offer, notes Richard Draves, manager of the lab's operating systems group. Says he, "You can pick up a phone and call up a friend in just about any group in the company because you've worked with them in the past."

Microsoft's commitment to such fusion was readily apparent last summer, when virtually the entire speech research effort—20 people in all—was transplanted to Building 25 to help the speech products group introduce improved speech recognition technology into a variety of applications. Leader Xuedong Huang had a core team up and working even before boxes were unpacked and remodeling completed.

Close interactions with product groups is just one part of the puzzle, however. Despite any talk of funnels, lab personnel cite their strong bonds with Microsoft's senior management as another key factor

Microsoft's late arrival at the Internet party may suggest big problems in the way research works at the company.

in keeping research on track. "At the very top ranks of the company people are technologists at heart—they love technology," says Daniel Rosen, general manager of Microsoft's New Technology group, which supplements Research by investing in or acquiring technologies from outside the company. In fact, Myhrvold and other members of Microsoft's powerful executive committee hold doctorates in mathematics or computer science. And that expertise, Rosen says, helps pave the way for the fruits of research to be integrated into products and overall corporate strategy.

Finally, unlike Bell Labs and IBM, where studies range from hardware to software, biology to physics, Microsoft's lab has a sharp and narrow focus. Outside of a four-person theory contingent, its 27 core groups focus on speech, natural language processing, graphics and other areas central to the future of personal computing. The result, lab managers believe, is a blue-sky lab with an "it's-cool-to-ship" attitude. Researchers are expected to advance the state of the art by publishing papers and speaking at technical gatherings. Rashid and Ling proudly cite the fact that 10 of 50 invited papers at the prestigious SIGGRAPH 96 conference were given by Microsoft's graphics gurus. But they're just as quick to boast the lab has contributed important code to virtually every company product. Proprietary creations include compression algorithms that allow more data to be stored on a disk, speech-recognition technology, an inference engine in Office 97 that makes troubleshooting easier, a video server and a host of development tools to facilitate programming.

Such feats—seemingly mundane in contrast to discovering laws of nature—mark a far different orientation from the old Bell Labs–IBM–Xerox PARC style of throwing inventions over the wall to development groups. Research managers say their product-centric mindset stems from the dual philosophy governing the lab. On the grand level, researchers are mandated to do for their fields what DOS and Windows did for the PC: Set the standards on which everything else rests. But fundamental developments may take years. The interim aim is to spin out products that help justify the lab's existence. Myhrvold sees such seedlings as a natural outgrowth of the lab's more lofty ambitions. As he says in true guru-like fashion, "You get more small ideas by thinking big than by thinking small."

Clouds of Doubt

IT'S A GOOD LINE. BUT WHILE ALL THE plans put in place to keep the lab's free-thinking researchers closely attuned to corporate aims make perfect sense, they do little by themselves to dispel the cloud of doubt that hovers over Microsoft Research.

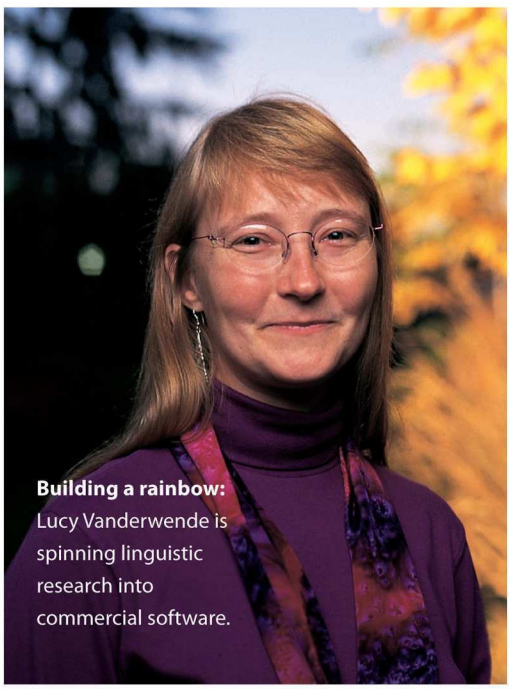
One question mark centers on how the government's antitrust suit against Microsoft might affect the company's research arm—especially if Microsoft were to lose. Myhrvold's lone public comment on the subject, quoted in the trade newspaper *Computerworld*, tended toward the dramatic: "What worries me is that if we create and innovate and discover something new, are we going to be able to let our customers have it? You'd think that would be a slam-dunk easy question, but that's not the world we live in."

While such a reading of antitrust law is not entirely out of bounds, historical precedent suggests a less dire outcome. Similar antitrust actions at DuPont, General Electric, AT&T, IBM and Xerox—most of which have forced the companies to change business practices—have not curtailed research organizations, says David Hounshell, professor of technology and social change at Carnegie Mellon. In fact, Hounshell notes, it's far more likely for antitrust pressures to *increase* the role of research. That's because outside acquisitions and licensing deals typically fall under increasing scrutiny, making it more desirable for companies to innovate from within.

DuPont, for example, endured eight federal antitrust suits between 1944 and 1963. But, says Hounshell, "during this period it dramatically expanded its research programs. Its executives saw research, and particularly fundamental research, as the only course open to it because it was under antitrust pressure. I would gather that executives at Microsoft are probably thinking a lot the same way." Witness Microsoft's decision last fall to open a lab in China and the mandate to reach 600 research staffers by 2000.

The other great mystery centers on the lab itself. Microsoft's upstart research arm clearly has a lot going for it. For one thing, as the universities and government labs responsible for many fundamental advances in computing scale back research, it is filling a vital void. Then, too, no one is contesting the ability of the people inside Building 31 to do some truly innovative work. "Nathan [Myhrvold] is a very imaginative guy, and he and Rashid are hiring some incredibly excellent people," says Xerox PARC's Brown. "There's no question in my mind that they're building up a first-class research operation."

But people alone will not carry the lab to greatness—and the lab's missteps on the Talisman and Internet fronts have to raise some red flags. "While they've certainly gotten a talented team of people together, there's not much you can point to in the way of output—and output has to be the measure of success of any research organization," notes James C. McGroddy, former director of IBM Research. McGroddy speaks on this topic with authority; he spearheaded IBM's campaign during the early 1990s to make the scientifically esteemed organization more relevant to Big Blue's businesses.



Building a rainbow: Lucy Vanderwende is spinning linguistic research into commercial software.

In the end, McGroddy and others who take a harder line still give the Soft at least a fighting chance of pulling off its research dreams. Michael D. Garey, director of mathematical sciences research at Lucent's Bell Labs, says that more and more he finds himself competing with Microsoft for top talent. He sums up the lab's prospects this way: "If they do it right, if they hire people and let a decent number of them do research that gets published in serious journals, then maybe one of these days the reality will match the PR story, and they will take their place among the premier industrial research labs." ◊

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JUST HOW THICK IS A VIRTUAL WALL?

You're getting ready to close your biggest deal to date via the Internet and the question of security crosses your mind (relax, it can be safe).

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Dropping in on a neighbor: A NASA artist's conception of the first manned Mars landing.

Missionaries to Mars

They gathered together to state the case and chart the course for a human voyage to Earth's red neighbor. *TR* got to sit in.

BY JAMES OBERG

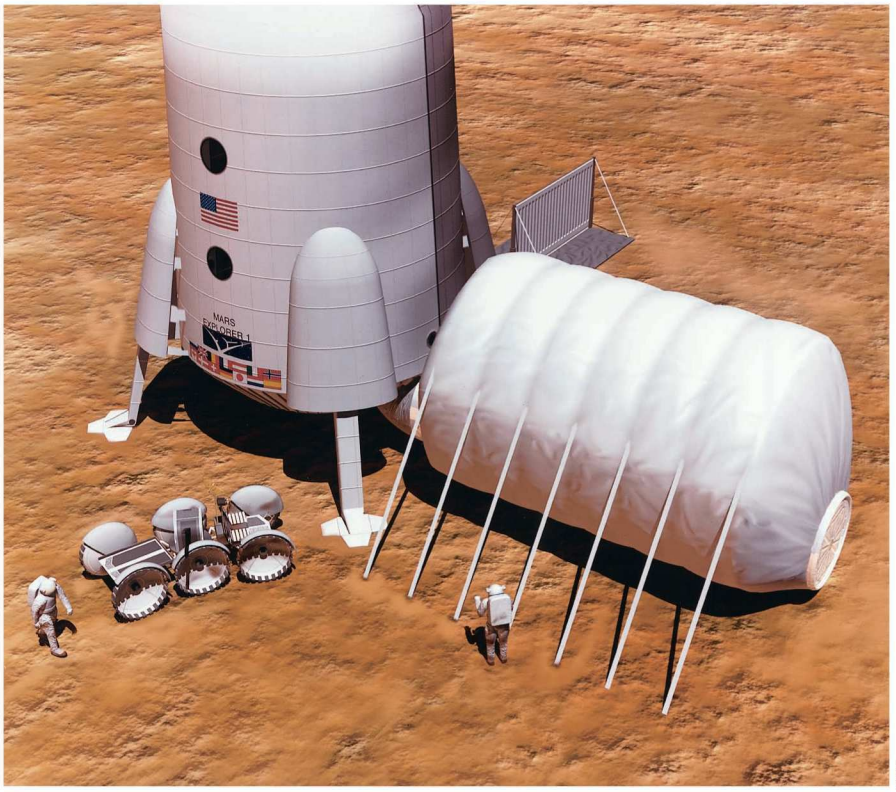
OUT IN THE ROCKY MOUNTAINS, YOU FEEL closer to space. The veil of air is thin; the stars and planets seem nearer. So it's fitting that the capital of the movement to send humans to Mars is at the University of Colorado in Boulder.

In the interests of journalistic full disclosure, I must note here that it's a movement I'm proud to be part of. Since 1981, I've gone to Boulder for occasional conferences of Mars flight enthusiasts; the most recent was last August. I still remember the very first "Case for Mars" conference, organized by a band of graduate students who had no idea what sort of reception their proposed convocation would receive. After all, the last government official to endorse manned flight to Mars had been Richard Nixon's soon-to-be-disgraced vice president, Spiro Agnew—an unfortunate patron saint.

In the early years of the Space Age, American citizens and aerospace engineers alike assumed that the moon landing was only the first step in an uninterrupted sequence of manned flights that would lead to Mars within 10 to 15 years. But in the '70s, post-Apollo retrenchment eliminated Mars from even the most optimistic NASA timetable; with the political perception that we had won the space race, NASA's budget was cut by two-thirds. The agency's remaining energies were concentrated on the space shuttle program, and manned flight to Mars vanished from official consideration.

Yet people came to Boulder in '81. They gathered hesitantly, almost shyly, with no official backing from any agencies or corporations. Many had kept the faith during a decade when talk of manned interplanetary flight was almost taboo. Each seemed astonished to see so many others stepping out of intellectual closets to proclaim that they, too, thought a human mission to Mars was feasible and desirable, and that they, too, had a new idea or suggestion to bring it closer.

But last summer, the conference brimmed with boldness. This time, more than 700 people gathered not only to exchange ideas, but also to form a new "Mars Society" and sign a "Mars Declaration" stating their belief that human flight to Mars had at last become feasible and was more desirable than ever. (That declaration has since been posted on their website at www.marssociety.org, and copies have been sent to Washington.) At the main podium, a parade of speakers delivered wildly imaginative presentations with the stated purpose of making all others look too moderate. The conferees were astonishingly eclectic: NASA scientists and astronauts; university researchers and graduate students; even ordinary citizens, some of whom brought their children. Vendors offered Mars T-shirts and Mars calendars.



NASA

Extraterrestrial outpost: The first Mars explorers might live in a two-story lander/habitat, work in an inflatable laboratory, and cruise the surface in an unpressurized rover.

Since the conference's planners, led by private-sector space engineer Bob Zubrin, founder of Pioneer Astronautics in Lakewood, Colo. *(see "Mars on a Shoestring," TR November/December 1996)*, were aggressively inclusive, the quality of the presentations varied enormously. Ideas were thrown around, thrown out and vigorously recycled. Specialized sessions dealt with everything from the engineering and medical challenges of a Mars mission to the legal and philosophical issues raised by human exploration of the planet.

Mooning Over Mars

IF HUMANS ARE TO MAKE IT TO MARS, HOWEVER, IT WILL TAKE much more than excitement. The successful flights of astronauts to the moon and back during the Apollo program of 1968 to 1972 rank as some of the greatest historical achievements of human technology; engineers overcame challenges in dozens of fields, including propulsion, thermal protection, communications and navigation, in a coordinated fashion. But the technological challenge of a manned mission to Mars represents a different order of magnitude.

Consider the basic numbers. One three-man Apollo mission used a single Saturn-V booster that placed about 120,000 kilograms of spacecraft and propellant in a low "parking orbit" just beyond the edge of Earth's atmosphere. After another rocket firing and a three-day voyage, two of the crew landed on the moon and spent several days venturing out onto the surface to collect specimens, take photographs and deploy instruments. Total mission duration for one of the Apollo flights was 10 to 12 days.

For Mars, many of these figures would go up dramatically. Most mission strategies require assembling a vehicle in parking orbit out of several components launched separately, adding up to 400,000 to 500,000 kilograms. The outbound voyage would last six to 10 *months*, followed by a sojourn on the martian surface lasting more than a year; during that time, crew members would make hundreds of trips outside rather than the three or four that Apollo spacesuits, tortured by rough usage and abrasive lunar dust, barely completed. The full mission would take close to three years and the astronauts' exposure to medical hazards such as long-term weightlessness and cosmic rays would be 100 times higher than it was for the lunar missions.

They stepped out of intellectual closets to proclaim that human flight to Mars was feasible.

So at first glance, a Mars mission seems as though it would be many times more difficult than the lunar landings, and consequently many times more expensive (in current dollars, Apollo cost about $80 billion). But in the view of experienced space planners and economists, space technology has already reached levels that would enable Mars missions at costs equal to or even less than those of the Apollo program *(see "Cheap Seats?" p. 57)*.

And Mars does offer certain advantages over the moon as a mission target. Drag from its atmosphere helps approaching vehicles slow

down without expending as much rocket fuel as needed on the airless moon. And Mars, unlike the moon, has plentiful supplies of water ice and gaseous carbon dioxide (raw materials for oxygen, hydrogen and hydrocarbon fuels). But developing the proper equipment to exploit these local resources is a daunting task.

In one of the splinter sessions at the recent Mars meeting, George James, a clean-cut young NASA engineer, described local resource utilization as "a defining attribute" of the agency's latest official Mars "design reference mission," a detailed plan drawn up to expose any hardware or operations problems with a proposed mission scenario. While NASA has not received an official commission to send astronauts to Mars, it has recently been conducting a series of such studies; NASA Administrator Dan Goldin speaks optimistically about the possibility of recommending formal approval for a Mars mission within a few years.

The scenario that James described called for the highly automated production of rocket propellant—methane—using elements culled from the martian atmosphere and a supply of hydrogen brought from Earth. With the dry enthusiasm typical of NASA spokespeople, he called the fuel production system "an effective performance enhancement" that appeared technically feasible in the near future; more advanced (and energy-demanding) systems to generate hydrogen from martian air or water would have to wait for subsequent missions.

NASA's innovative strategy would exploit recent advances in automation and remote control to operate a propellant extractor on Mars long before the crew arrived. If this system were implemented, even before astronauts left Earth their return vehicle would be waiting for them on Mars, its tanks already filled with martian-manufactured fuel. And, in addition to rocket propellant, local production plants could create fuel for surface transportation and for electricity-producing fuel cells. Studies conducted by NASA and by Bob Zubrin's team (for their "Mars Direct" plan) show that even a modest use of local production strategies cuts the required weight of the Mars-bound spacecraft by half or more.

Building laboratory demonstrators of such chemical processes is one thing, but designing hardware to last for years in the martian environment is a challenge of a much higher order. Yet some designers have advanced to the stage where they must now deal with such practical considerations; prototype hardware is already being built for testing in special simulation chambers that will mimic conditions on Mars, as knowledge of those conditions grows.

"It's frightening how much we don't know about the real martian surface environment," another NASA engineer told a small breakout session. Tom Pike, a planetary geologist at the Jet Propulsion Laboratory (JPL) in California, described an experiment called MECA—for "Mars Environment Compatibility Assessment"—that's scheduled to fly on a lander in the next few years.

The effects of dust on hardware is of great concern, Pike explained: "Fine particles are blowing at speeds up to 300 kph, and that will cause electrostatic charging, but we don't know how much." Dust will clog chemical recycling canisters, stick to windows and solar cells, and abrade moving parts. What is more, it will inevitably get inside the human habitats, and inside the bodies of the crew members. "What happens when it gets hydrated, or oxygenated?" Pike asked. "Is it flammable, or toxic? Is airborne dust different from surface dust, or different from subsurface dust?"

Nobody even knows the acidity or alkalinity of the martian dust, or its composition—factors that could pose serious threats to the Mars explorers' health. But hardware to answer these questions, including a microscope and a sample/chemical mixing station—is now being built in JPL workshops.

On a Wing and Thin Air

WHILE MARS ENTHUSIASTS MAY NOT YET KNOW ENOUGH ABOUT the martian soil, they already know one important thing about the martian air: It is very thin. And though the martian atmosphere has less than 1 percent of the pressure of Earth's atmosphere at sea level, a few aerospace engineers are drawing up blueprints for small unmanned airplanes capable of flying across vast expanses of the martian terrain. Such a plane's instruments could survey complex geological regions, including many that look too rough for surface rovers.

Larry Lemke, a robotics expert from NASA's Ames Research Center in California, told a plenary session about one winged mission. A 150-kilogram vehicle with a 10-meter wingspan, on the scale of a powered hang glider here on Earth, would be launched from Earth folded inside a probe. After the probe entered the martian atmosphere, it would drop its heat shield and pop open a small stabilizing parachute. The airplane would unfold itself during the descent, and detach from the parachute for its free flight. The winged robot could carry 20 kilograms of instru-

Cheap Seats?

Mars is a much more remote target than the moon, and intuition dictates that the price tag for a manned mission to the planet should be correspondingly higher. In 1999 dollars, the Apollo program came to about $80 billion. So when President Bush proposed a "Space Exploration Initiative" (SEI) in 1989 that included a lunar base and Mars expeditions, nobody was surprised when the price tag came in at just under half a trillion dollars. Nor was anybody surprised when sticker shock killed the proposal deader than lunar soil.

More sober estimates, however, have always been lower. Since so much space infrastructure (such as launch pads, vehicles and communications and control facilities) has already been developed and paid for (unlike in Apollo's time), the add-on costs of the Mars mission become much less shocking. Using a unit of "Apollo" (the total cash cost of the moon program), NASA analysts who weren't in the original SEI study group have long argued that a human Mars landing would be in the very manageable range of one-half to one Apollo. Based on detailed costing techniques that have proven accurate in the past, and using the most recent mission profiles, the best guess by these NASA and space industry experts is that a program would cost about twice what the International Space Station is currently spending, or about $4 billion to $5 billion per year.

One credible explanation for the hideous $450 billion price tag for Bush's SEI was offered by one of the conference organizers, space engineer and Mars enthusiast Bob Zubrin. Basically, Zubrin believes, the representatives of the different NASA centers got together, listed all of the dream projects they had always wanted to do, and all agreed to scratch one another's backs. As a result, most of the price tag was devoted to open-ended developmental projects whose utility for a Mars expedition was questionable at best.

ments, including an infrared pointed spectrometer to map mineral and ice deposits, and a suite of geophysical field instruments to spot traces of the planet's geological history. Lemke's team has already charted a 2,000-kilometer, three-hour course down Mars' Vallis Marineris canyon (which is longer than the United States is wide).

The thin martian air, Lemke insisted, would not be an issue. At the planet's surface, he pointed out, Mars' air pressure is about the same as Earth's at 24,000 meters' elevation. Since NASA's unmanned solar-powered "Pathfinder" aircraft routinely cruises at this altitude on Earth, it provides the proof of concept that a more specialized vehicle could also fly on Mars. "Aerodynamics is not a problem," Lemke told the meeting.

Nor is technology a problem, Lemke said. "The Mars airplane has benefited from a lot of technological advances over the last 20 years from areas with no connection to astronautics. There has been work in radio-controlled aircraft, in lightweight structures, in electric propulsive motors, and in military deployment systems."

The concept is so viable, Lemke believes, that he is calling for a launch in the year 2003, to celebrate the centennial of the Wright brothers' first heavier-than-air flights. "We should mark the 100th anniversary of the first airplane flight on Earth with the first airplane flight on Mars," he said.



SOURCE: NASA

BETSY HAYES

A Window on Mars

Even if the rockets, spacecraft and astronauts are ready, a journey to Mars cannot begin until the planets are in alignment. The logic sounds astrological, but in fact it is mathematical.

Relative to the sun, a spacecraft before launch is already moving at Earth's orbital speed. To take the most economical path through space, the craft's engines must add to the orbital speed, throwing the vehicle onto an elongated orbit that reaches farther from the sun than the Earth does. If (and only if) the farthest point on the elongated path intersects Mars' orbit at just the right place and time, the craft will be able to reach the planet.

As Earth and Mars circle the sun like lapping race cars, they repeat the proper relative "starting positions" for such a rendezvous about every 26 months. Then, during a "launch window" of only a few weeks, travelers can follow the most efficient path from Earth and arrive at Mars six to 10 months later. Timing is similarly tricky for the return journey; to take the best path home, Mars explorers will have to wait on the planet for 15 to 20 months until the next window opens.

As a result, using so-called "minimum energy" trajectories requires a mission time of more than two years, far longer than humans have yet endured in space. Shorter missions are possible if the craft carries more fuel (an added expense), or if special slingshot shortcuts past Venus can be built into the trajectory. But even under the most optimistic designs, mission durations are still 18 months or more.

Powering Up

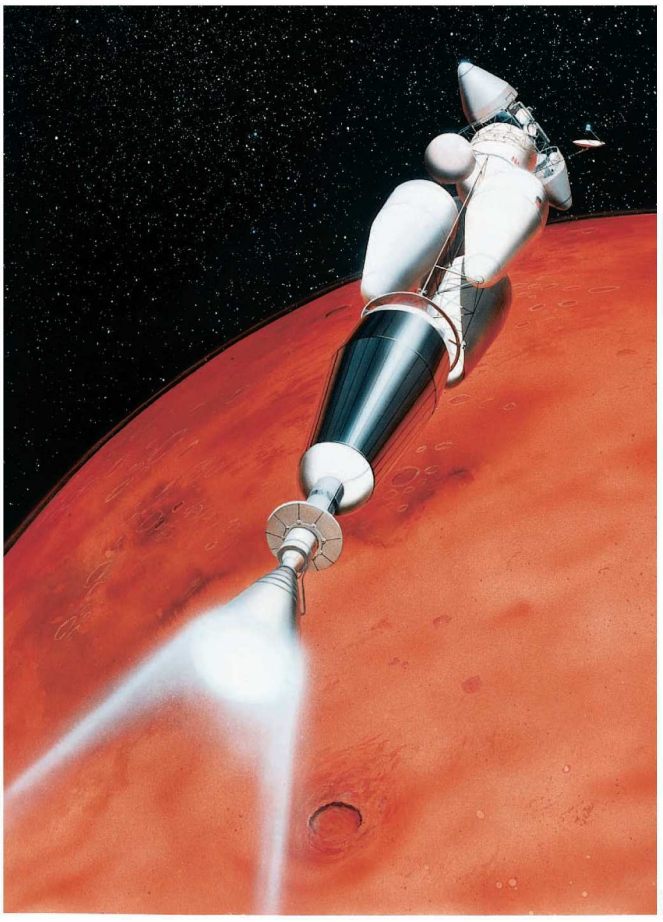
WHETHER ROBOT AIRPLANES FLY ON MARS OR NOT, FOR HUMAN voyages a key consideration will be the power plant that gets the explorers there. One possibility that was considered at the Mars meeting was nuclear power. The nuclear-powered rocket has been a mainstay of science fiction for generations, and in the 1960s the Atomic Energy Commission actually designed and tested several uranium-235-powered prototypes to serve as upper stages in space. By ejecting superheated hydrogen gas, they provided thrust as strong as chemical engines of similar size, but could get that same thrust while expending only half as much fuel mass. This efficiency would have been a tremendous advantage for the heavy manned Mars vehicles then under consideration.

Indeed, space nuclear power was the theme of several of the breakout sessions at the conference. The session I attended met in a windowless classroom in the basement, and was led off by Roger Lenard, an engineering manager from the Department of Defense's Sandia Labs in Albuquerque, N.M. Lenard has advocated the use of nuclear power in space since his stint as director of the Timberwind project, a nuclear-powered anti-missile system designed as part of the "Star Wars" defense system. But Timberwind collapsed a decade ago under bad publicity over potential environmental impacts—firing it in combat threatened to contaminate large areas of the Pacific Ocean, including New Zealand.

Despite such concerns, nuclear power has remained popular in the imaginations of a core group of specialized engineers, and enthusiasm for extraterrestrial use of nuclear energy reached critical mass at the conference. Space nuclear advocates such as Lenard have been waiting for decades to get a mission approved, and they believe Mars is their best chance. By targeting a planet too far away to be considered anybody's backyard, they hope to sidestep the "not in my backyard" attitude of anti-nuclear activism.

Lenard criticized what he saw as NASA's tendency to avoid the subject of nuclear power because of its controversy. And even within NASA Mars mission studies that include nuclear power, he found what he considered to be unrealistic design constraints. In 1989, Lenard worked with NASA as a nuclear power specialist on a Mars design reference mission. That project included a single bimodal nuclear reactor, which first provided propulsion for beginning the Earth-to-Mars leg, and then provided electric power during the trip and on the surface. But bimodality is a bad idea, Lenard argued. "The design demands of a good propulsion system are antithetical to the design demands of a good power system," he said.

Propulsion systems require a temperature as high as possible—3000 K—and operate for only a few hours at a time. "And



NASA

Politically problematic propulsion: A nuclear rocket, such as the one depicted here powering a spacecraft into orbit near Mars, could shorten travel times and reduce the mass launched from Earth. But space nuclear power faces a long history of bad publicity.

you don't worry a great deal about retaining all fission products," he added, since they fade safely into the already-radioactive background of space. In contrast, providing electrical power (both in flight and on the surface) requires only modest temperatures and modest efficiency, but the system must operate over long periods.

In Lenard's analysis, other Mars enthusiasts haven't thought these issues through. "They presume that one development program for a reactor that does two or three things is automatically cheaper than two or three separate programs," he told the packed room. "But we reject that. When the requirements are so mutually exclusive, this becomes a program with enormous risk, with long lead times and high cost."

Still, excepting the wild card of political acceptability, nuclear technology is the top contender to power a Mars mission. Without nuclear propulsion, early manned missions to Mars would have to rely on chemical engines, making the vehicles larger and perhaps doubling the freight bill for getting a ship into orbit. More exotic non-nuclear systems capitalizing upon such concepts as "inertialess propulsion" and anti-gravity remain wildly imaginary and decades in the future at best.

Life on Mars

ALTHOUGH POWER IS CLEARLY A CHALLENGE FOR A MARS MISSION, as I moved from session to session and seminar to seminar, I began to see that there is another area that represents the core of the challenge—and it's not really a technological problem. When the Apollo missions went for the moon, it was hardware that was most crucial—the rockets, the navigation, the crew control systems and even the rocks that were the mission's goals. But with Mars as a destination, the focus kept falling on life.

For a successful manned mission to Mars, many different aspects of the meeting suggested, we must consider life on many scales. Microscopic nano-fossils may indicate past life on Mars, and will be a prime objective for exploration. At the level of medicine, we must determine how to preserve human health under flight conditions. In sociological terms, we will need to understand the proper mix of crew skills, and the proper crew organization for multiyear missions beyond the range of radio conversations.

Radio signal round trip time ranges from eight to 30 minutes, depending on how far apart Mars and Earth are at any given time, so today's earthside frustration with playing voicemail tag will become the norm for Mars travelers. In a simple demonstration of a communications delay using banks of video recorders and periodically swapped cassettes, I organized an exercise in which attendees at a 1997 medical conference in Houston faced a simulated medical emergency on Mars. As actor-astronauts followed a checklist of responses to the crisis, the earthside medical team had to learn to anticipate the martian team's needs and progress.

Amazingly, both the terrestrial and extraterrestrial teams adapted within an hour to the interplanetary rhythm, providing adequate questions and answers in a surprisingly efficient fashion. But the exercise only used a four-minute delay, and the scripted medical scenario was well defined. Future experiments will have to address more realistic delays and more unpredictable scenarios, as space planners prepare for the temporal challenge of Mars.

The communication challenges of the Mars mission also apply to the folks left behind on Earth. In the realm of politics and diplomacy, we must muster the national perseverance and international cooperation needed for such a long-term project. On the interplanetary scale, we should consider quarantine standards to protect Earth from any extraterrestrial life forms that might hitch a ride home from Mars. Finally, on perhaps the universal scale, I saw impassioned argumentation about the desirability of and the strategies for someday modifying the climate of Mars to make it more earthlike—in other words, to "terraform" it. Only a few of these issues were at all significant during the 1960s moon landings, but many of them would become critical to a successful human mission to Mars.

And that may be the key to securing government commitment to such a project, for such questions of life resonate on Earth, as well as in space. It seemed to me that a human Mars program—not just a one-time "flags and footprints" dash but a sustained sequence of expanding expeditions—could result in the same sort of broad-based technological invigoration that the Apollo challenges fueled 30 years ago. If designed properly, this bold project could accelerate innovative research also applicable to terrestrial problems, both known and as yet unknown.

But that was an argument for the politicians and the bean counters at the federal budget office. At the conference I was surrounded by people already persuaded, as I am, that the project is desirable, even urgent. And although Mars was not visible to the eye that week—it was just emerging from the sun's glare in the pre-dawn skies—its image burned brightly in my mind. To me, in an inversion of everyday traffic rules, the red light in the sky signified "Go!" ◊

TECHNOLOGY UPDATE

Technology that can change the way you live and work.

Just take a look at the new products that can help you: **enjoy restful, therapeutic sleep...heat your home evenly and efficiently...spot weather trends before the forecasters...and start a drained battery without opening the hood of your car.** They represent the world's latest technology, and you can try them risk-free with our exclusive home trial.

We knew the storm was coming before the Park Rangers did"

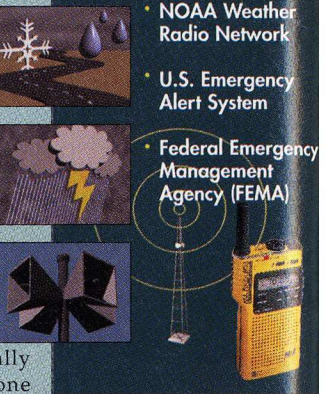
All Hazards Weather Radio provides continual weather and emergency monitoring and has a variety of helpful features.

Until now, there has been no single source for immediate, comprehensive weather and emergency information, available to the public, in advance of TV and radio bulletins. Oregon Scientific, a leader in personal electronics, has created a special radio that is ideal for traveling, as well as for campers, hikers and everyone who needs to be prepared for weather emergencies in the great outdoors. It monitors the U.S. Emergency Alert System and automatically seeks all seven frequencies used by the NOAA (National Oceanic and Atmospheric Administration) Weather Radio system. This network broadcasts 24-hour weather forecasts, weather-related travel conditions and warnings about imminent severe weather conditions.

Automatic alert. In the event of special warning broadcasts, the radio's innovative alert system automatically activates a loud tone

UPDATES AROUND THE CLOCK

- NOAA Weather Radio Network
- U.S. Emergency Alert System
- Federal Emergency Management Agency (FEMA)



Bring a drained battery back to life without opening your hood

The remarkable Auto Starter® eliminates the need for dangerous jumper cables and can provide independent power for a variety of uses.



Imagine this...after a long flight home, you arrive at the airport parking lot, get in your car and turn the key. Nothing happens, not even a click. Guess what? Your car battery's drained. It's cold, dark and you're alone. Do you flag down a stranger and hope he has jumper cables? Do you walk back to the airport, phone a tow truck and wait? No...you simply reach into your glove box and take out your Auto Starter®. You plug it into your car's cigarette lighter and, in a matter of minutes, you're on your way.

A good start. These days, cars have complex electrical systems which increases the risk that someday you'll find your car's battery drained...no horn, no lights, not even a click from the solenoid. Before Auto Starter, you either had to call a tow truck or try to get a jump from another vehicle. Jumper cables, even heavy-duty ones, are dangerous and involve getting under the hood. Plus, there has to be another car around to provide the jump. If the cables are not connected correctly they can damage your car's expensive electrical system or, even worse, cause an explosion. With Auto Starter, you don't need a jump—you don't even have to open the hood. You simply plug the unit into the cigarette lighter, wait a few minutes and you're on your way. Leave the unit plugged in for 30-120 minutes while driving and it recharges automatically.

The five-amp sealed alkaline battery operates under extreme temperatures, from sub-zero to 120 degrees. It is less than eight inches long, so it stores easily in your glove box. Once it's charged, Auto Starter will retain the power to start your car for five years. It is the easiest, most convenient protection you can own.



The Auto Starter eliminates the need for another car to give you a jump, and gives you a portable 12-volt DC power supply!

- *No getting out of your car*
- *No opening the hood*
- *No jumper cables*
- *No tow trucks*
- *No flagging down strangers*
- *Portable power...anywhere*

Portable power. Auto Starter has many other uses. It's an independent 12V DC power supply that can operate TVs, radios, cellular phones and laptops. Almost any appliance that runs off of an adapter can operate independently with Auto Starter.

Auto Starter also makes it easier to work on your car. Plug it in before you change the car battery, and you won't have to reprogram your car's clock, radio or alarm system. You wouldn't think of driving around without a spare tire—why not have a spare battery and alternator that fits right in your glove box?

Try it risk-free. Considering the cost of a tow, Auto Starter will pay for itself the first time you have a problem. This product is backed by a one year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If you are not fully satisfied for any reason, return it within 30 days for a full refund, "No Questions Asked."

"For years I had trouble sleeping restfully—now I know the problem was in my mattress!"

NatureSleep™ Platinum features comfort zones that match your body's shape and promote restful, therapeutic sleep.

Traditional mattresses leave your lower back and legs unsupported and hinder proper circulation. Even expensive waterbeds, which are supposed to distribute weight evenly, fail to support the body properly. Your spine arches downward, in a position specialists refer to as "hammocking," causing excessive strain on the back. Scientists and doctors agree that the ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind NatureSleep Platinum, the revolutionary product that turns any bed into the ideal sleep surface.



The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure.

Scientific solution. Anatomic Concepts, a medical product research and manufacturing company, has designed the ultimate mattress pad. Using research originally

nd a flashing red LED indicator. If the radio is in silent standby mode, it even turns on the speaker. Emergency bulletins might include alerts for tornadoes, hurricanes, earthquakes, ice and snow storms, thunderstorms and other severe weather as well as other emergencies that require immediate public notification.

Important features. The radio incorporates a variety of special features geared for outdoor use. These include a built-in analog compass, ambient temperature display and an audible/visual Freeze Warning Alert. The digital display incorporates a clock with alarm and snooze controls. A switch lets you turn the speaker to ON or MUTE, or you can set the unit to stand-by mode. The unit's water-resistant case is rugged and durable, and there's even a built-in belt clip and desktop stand. Its compact, lightweight design makes it ideal for almost any situation, and it operates on 3-AA batteries.

Try it risk-free. The All Hazards Weather Radio comes with a one-year manufacturer's limited warranty and Comtrad's risk-free home trial. If for any reason you are not satisfied, simply return it within 90 days for a full refund.

B



conducted for hospitals, this innovative company developed an effective, affordable way to transform any mattress into a specially-designed sleep surface that closely matches the shape of the human body. It features a patented five-zone sleep surface that holds the body in a neutral posture and redistributes pressure during sleep.

C



✔ A unique, high support factor design for more comfortable, restful sleep.

✔ Comfort zones match your body shape. Built-in lumbar support reduces spinal stress and backaches.

Comfort zones. The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure. Until now, only the most expensive and most advanced mattress products featured this degree of technology, but now you can get it without even buying a new mattress.

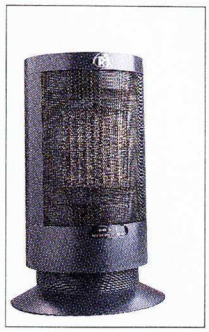
Installs in seconds. NatureSleep Platinum fits right over your existing mattress, uses normal sheets and turns any bed into an anatomically-correct sleep surface. The five comfort zones have been created using a computer-designed grid pattern and are engineered to accommodate people of all heights and sizes.

Risk-free. Try it for yourself, it comes with a one-year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If for any reason you are not completely satisfied, return your purchase within 90 days for a full refund, "No Questions Asked."

The efficiency of ceramic warmth combines with oscillation to create the perfect heater...

D

This compact heater uses a genuine ceramic heating element and an oscillating fan to eliminate cold spots and provide intense warmth throughout an entire room!



If you could build the perfect heater, what features would it have? A safe, yet effective, heating element? A thermostat that would let you select a desired comfort level? An effective way to disperse the heat throughout an entire room? Safety features like automatic tip-over and overheat protection?

Royal Sovereign recently unveiled a remarkable new heater that combines a ceramic heating element with a solid-state thermostat and an oscillating fan—its called the RST-1200 Oscillating Heater.

Ceramic advantage. The RST-1200 utilizes a genuine ceramic heating element. Ceramic elements are known to be a very efficient and effective heating method. Ceramic heaters do not burn air—therefore, they do not cause any odors or produce any unwanted side effects. Even more important is the fact that the RST-1200 does not get hot to the touch—so it is not a fire hazard.

Control your climate. The RST-1200 has an electronic thermostat that lets you choose your own comfort level. Simply set the dial to the appropriate temperature, and the RST-1200 will automatically maintain that comfort level. It provides even, uniform heat—without irritating hot/cold cycles.

Spread warmth throughout a room. The RST-1200 oscillates over a range of 70°. A high-velocity fan disperses the intense warmth resulting in even distribution of the heat. The RST-1200 will eliminate cold spots, even in those rooms with poor ventilation!

The oscillating difference.



The RST-1200 is unlike ordinary space heaters. Because it oscillates over a range of 70°, the RST-1200 spreads the warmth created by its genuine ceramic heating element evenly throughout your room, eliminating cold spots. And with its solid-state thermostat, you can set a specific temperature, and the RST-1200 will maintain it effectively and efficiently.

Safety features. The RST-1200 may be the safest space heater you can buy. Its cool-touch cabinet prevents the RST-1200 from being a fire hazard. The RST-1200 also has built-in, automatic overheat and tip-over protection. The unit will shut off if tipped over, airflow is blocked or anything is spilled on it. A red safety light indicates that the unit has shut itself off for some reason. The RST-1200 is so safe you can let it run 24 hours a day, worry-free!

Try it risk-free. The RST-1200 Oscillating heater is backed by Comtrad's risk-free trial. Try it, and if you are not completely satisfied, return it within 90 days for a full refund. It also comes with a one-year manufacturer's limited warranty.

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The FBI has struggled for decades to automate its vast and cumbersome collection of fingerprints. A new system is set to come online in July... but it could be obsolete even before it's introduced.

The Tide of Prints

BY ERIC SCIGLIANO

PHOTOGRAPH BY FREDRIK BRODÉN

THOUSANDS OF TIMES EACH DAY ACROSS THE UNITED STATES A POLICE OFFICER BOOKS a suspect, stops a suspicious character near a crime, or pulls over a speeder, and takes his fingerprints. Or he pulls "latent" prints from an object at a crime scene. He zips the prints to a central fingerprint database, and gets an answer back immediately. The prints reveal what the suspect's false name and identification concealed: He has outstanding warrants, or a rap sheet as long as the arm of the law. Or worse: He's an escaped felon, armed and dangerous. That information will enable the police and courts to hold him—or save the life of that lone cop, who might otherwise be ambushed.

That's the fantasy, anyway. Now, the reality: When police pull prints, they may indeed be able to make a speedy identification—if they can match the prints in their own city's or state's databases. Every state except West Virginia, where the Federal Bureau of Investigation's own identification operations are located, has a computerized "automated fingerprint identification system," a.k.a. AFIS. Police in one of the West Coast states connected to the Western Identification Network may be able to find a match among neighboring states' databases. But as law enforcers never tire of observing, crime doesn't honor borders. If it can't match a print in its own or its neighbors' files, a state must mail it to the mother of all fingerprint repositories—the FBI's 227-million-card (that's right, card) collection—and wait a month for a response.

On July 30, this logjam is set to be dynamited. On that date, after 10 years' development and decades of false starts and dead ends, the FBI's Integrated Automated Fingerprint Identification System (IAFIS), far and away the world's largest and most complex such system, is due to come online. IAFIS promises to turn around criminal print searches in two hours and civil searches in 24. Even before the system starts up, however, its built-in limitations are becoming evident—and are threatening to grievously undermine its value for some of the crime-busters who will depend upon it most. And already the possibility looms that this centralized system, the product of an epic development saga, may soon be superseded, either by new "biometric" identification technologies *(see "Beyond Fingerprints," p. 65, and "Secret Handshakes," p. 66)* or by dispersed PCs that can do the same job at a fraction of the cost.

In the first half of 1998, police around the United States unwittingly released more than 5,000 fugitives because fingerprint IDs didn't come back in time.

Storing and identifying fingerprints has been central to the FBI's mission almost from the start. When J. Edgar Hoover became director and set out to expand the bureau in 1924, Congress directed that it take over and integrate the nation's scattered print files.

The dream of instant identification via fingerprints was born just 10 years later, when the FBI tried to automate its fingerprint files by recording ridge counts (one of the most basic fingerprint measures) on punch cards. But 1934's analog computers could only sort the cards into general classes, not match individual prints. The effort was soon abandoned—except in the movies. Hollywood, which hyped the bureau's abilities long before *The X-Files*, recycled footage of G-men punching in fingerprint searches for decades.

Nevertheless, the bureau continued to be revered as the pacesetter in the arcane science, and art, of fingerprint identification. It refined the elaborate turn-of-the-century Henry System for classifying prints according to numerical values derived from their patterns of loops, arches and whorls, and built a massive mechanical beltway for transporting its millions of cards. But the FBI became the captive of its own early successes, anchored to obsolete approaches while the rest of the world went digital.

Arrested Development

CLEAR BACK IN THE 1960S, SAYS PETER HIGGINS, A FORMER FBI deputy assistant director for information-services engineering, "J. Edgar Hoover decided it was about time the bureau started doing something with computers—and do it in six months or less." In 1967 it launched the National Criminal Information Center (NCIC) and began developing digital fingerprint readers. When the first operating models arrived 10 years later, the bureau proceeded to scan in its millions of "ten-print" fingerprint cards. But search capability lagged, and the FBI struggled through the 1980s to increase that capacity while automating document flow and transport. The bureau continued to rely on a hybrid paper/online system, much of it still in use today, based on 1970s technology that was obsolete when it was installed.

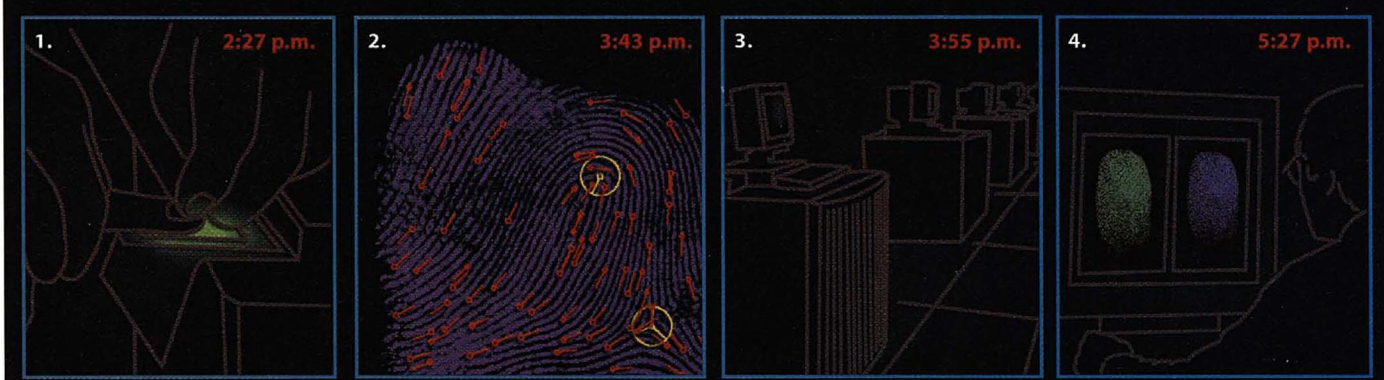
The typical sequence: A local police department mails its fingerprint cards to its state's AFIS, which, failing to make a match, mails it on to the FBI. There, one of the bureau's nearly 800 expert fingerprint examiners determines the print's Henry classification. File prints of that classification are called up and a computer compares the mystery print's minutiae—points where ridges end or branch—against theirs. The computer proposes a candidate match, which one examiner checks and another verifies.

Under this labor-intensive regime, it takes the bureau about 33 days to turn around a criminal fingerprint search. The delay is even longer at the other end—the police and other agencies that supply the prints of criminals, government job applicants and other subjects to be entered in the national database. A mid-1990s FBI survey found it takes them on average 118 days to process and mail in prints of newly arrested suspects. Paper shuffling eats up time, and agencies may not give priority to supplying a system they know will be slow to respond anyway. Not only will a suspect be released long before his prints show up in the system, he'll have ample time to, say, buy a gun or get hired by a daycare center.

One result of this double logjam: In the first half of 1998, police around the country unwittingly released more than 5,000 fugitives because fingerprint IDs didn't come back in time.

Even as the bureau struggled in the 1980s to meet soaring identification demands, the private sector and local governments leapt ahead. Several companies capitalized on the FBI's early innovations to build truly automated AFIS equipment. As Kevin Wilkinson, a special assistant in the FBI's Congressional Affairs Office

Digital Revolution at the FBI



1. Jane Doe is booked under a pseudonym for a minor offense, and her fingerprints are taken digitally. Neither her prints nor her fake identification information turns up in local and state systems, so her file is forwarded electronically to the FBI for analysis in the agency's new system. 2. At the FBI, computers cannot locate Jane's alias, but they can pinpoint the "minutiae" of her fingerprint—ridge endings and bifurcations that uniquely identify each individual. 3. A network of parallel computers queues the request, then checks the selected features in Jane's print against millions of others in the FBI's database, and suggests a short list of candidate matches. 4. An examiner checks the first candidate against Jane's print—it's a hit. A second examiner verifies the identification. FBI records show an outstanding warrant for her arrest (under her real name) in another state. A report goes out to local authorities.

BETSY HAYES

who worked in the Identification Division in the 1970s, recalls, "the technology leapfrogged in a massive way" over the bureau's own. States and cities, exasperated with the FBI's slow progress, bought commercial AFIS rigs. Some have progressed to fully automatic "lights out" fingerprint transmission and searching, so called because no eyes need watch until the computer spits out the result.

Digital Perestroika

WITH THE FBI'S IDENTIFICATION DIVISION SHOWING SIGNS OF terminal obsolescence, an outcry arose among those who most rely on it: the cops. The conduit for their dissatisfaction was the FBI's NCIC Advisory Policy Board, which represents police and prosecutors nationwide. The board tendered a plan in 1989, drafted by Joseph Bonino, the Los Angeles police department's identification-division commander, that set the bureau on its current path.

The Policy Board report urged a fresh start; a proposed update of the existing hybrid system would throw good money after bad. Since the states had already proven that AFIS works, the FBI should go straight to it without a superfluous trial. Most important, it should dump the Henry classifications, which the bureau had honed into such an exquisite old-tech tool; with computing power now available to sort prints according to general features and extract and search minutiae directly, Henry's day had passed.

The FBI got this message and ran with it—straight to Congress, where the money is. In May 1990, FBI Director William Sessions testified that "the time is rapidly approaching when the FBI will no longer be able to provide [the] vital service of forensic identification." Congress heard, and responded with $640 million for the all-new IAFIS and more than $2 billion to overhaul the whole FBI information apparatus.

Under IAFIS, law enforcement officers will still be able to mail in paper print cards, but to get the benefits of real-time searching the FBI will encourage them to submit the prints electronically. Typically, a suspect's fingerprints will be scanned at one of the electronic booking stations being deployed (at around $100,000 a pop) at police precincts throughout the nation. The digitized prints, along with the suspect's name and description, will be transmitted to the state's AFIS. If the state system can't find a match, it will transmit the inquiry to the FBI's Criminal Justice Information Center (CJIS), via the CJIS wide-area network. IAFIS assistant program manager Thomas J. Roberts estimates that state processing of an image will typically take at least an hour. At the FBI, an operator will check the quality of the submission and launch a name search in IAFIS databanks. If that fails to yield a hit, IAFIS will automatically begin seeking a match for the subject's prints.

Developing a search engine powerful enough to do this—to scour a database of 32 million-plus digitized "cards," each comprising prints from all 10 fingers and containing 750 kilobytes of data after compression—was key to the whole IAFIS effort. The contract for this engine went to Lockheed Martin (then Martin Marietta), a defense contractor that had no experience in identification systems but much in computer imaging and in managing complex projects. Lockheed Martin radically rethought the search process. Instead of undertaking three search stages—a rough match, fine match, and score—as predecessors had done, it designed two separate searches with different algorithms, and then a fusion algorithm to merge the two results; what one misses, the other catches.

In standard ten-print searches, this search engine will initially concentrate on the first two fingers of a subject's right hand; if

Beyond Fingerprints

Even as the FBI finally realizes fingerprinting's potential as a crime-fighting tool, a slew of other biometric identification technologies—nearly as diverse as the body's scannable parts—wait in the wings. Among the contenders:

Finger and hand geometry (reading outlines, not prints) is a quick, sturdy means of verifying identity for such applications as a workplace punch-in. But as James Wayman, executive director of the National Biometric Test Center, explains, hand geometry is prone to making false matches, and is thus a bad choice for ID searches.

Facial recognition has already been used in venues as various as border crossings and corporate computer access. The term actually embraces several different techniques: video or photo imaging, thermography (reading the heat pattern given off around the eyes and cheeks), and scanning the head's dimensions. Facial scanning can be done so inconspicuously that Visionics of Jersey City promotes its FaceIt as a surveillance tool for capturing every passing face in "a time-stamped database." But it doesn't come near fingerprinting's accuracy; similar faces, changing light, a shave or a haircut can all throw off a facial scanner.

Iris recognition is also inconspicuous enough to be secret—and, boosters claim, perhaps more accurate than fingerprints. Video images are digitally processed and compared according to the light and dark patterns at selected points in the irises' flecks and rings. New Jersey-based Sensar plans to have its infrared iris scanners in automatic-teller machines late this year. **Retinal scans** are more intrusive, requiring close-up infrared scanning through the pupil. Some sensitive government installations use retinal scans at their entries, but don't look for them soon at your ATM.

Handwriting recognition *(see "Secret Handshakes," p. 66)* is a tricky, specialized business, requiring a block of text. But active signature recognition works—as its name implies—with just a signature, "read" on an electronic pad that measures the speed, pressure and direction of strokes. This fast-developing technology's accuracy is still a subject of debate, but it can at least foil forgers who can now produce flawless electronic hard-copy signatures.

Voice recognition extends biometric identification and surveillance to the telephone. Early applications include home-detention monitoring and password-style security screening; T-Netix of Englewood, Colo., sells its voice recognition software to many national and local phone companies. But the technique is susceptible to background noise and changes in voice quality, so wait till you have a cold to make calls you don't want traced.

The type of biometric identification most trumpeted and most feared is **DNA matching.** Last October the FBI's Laboratory Division launched CODIS, "Combined DNA Index System," a national DNA database linking all 50 state databases. CODIS contains 120,000 of the 600,000 DNA profiles so far collected in criminal cases, primarily sex crimes. "We're designing it to accommodate millions," says CODIS manager Stephen Niezgoda.

CODIS has some privacy safeguards built in: It only records case numbers, not names, of subjects (all convicted criminals) and only analyzes the "nonsense" regions of their DNA. Niezgoda foresees an explosive growth in both the technology and use of DNA screening. Already, he says, the British police find it cheaper to conduct "DNA sweeps"—for example, screening all potential suspects in the vicinity of a sex crime—than to do traditional police work.

prints of these are missing or indistinct, it will automatically seek a good image among the other digits. And the engine will set weighted parameters for its search based on the suspect's sex, race, age, scars, tattoos, and other physical and demographic features; it will put less weight on features that are often wrongly estimated (such as weight) or easily changed (hair color).

By thus tailoring its searches, IAFIS will be able to find a match in a fraction of the two hours that the bureau allows itself for each criminal print search. Most of that time will go to an electronic version of "Hurry up and wait" necessitated by IAFIS's already anachronistic data storage hardware. As every computer shopper knows, hard-disk capacity has mushroomed in the decade since IAFIS and CJIS were conceived. In 1990, CD-ROM was the storage standard. IAFIS files are therefore contained in a phalanx of CD jukeboxes holding a total of about 10,000 disks, each containing images of about 3,000 fingerprints. As Roberts explains, 62,000 searches a day (the number anticipated once IAFIS is up to speed) would "thrash" this hardware. And so the search engine has an intelligent work manager that will automatically queue searches, ganging together as many as possible for each jukebox and CD.

Once the search engine finds a single hit or short list of candidate matches, these go to a human examiner who checks or selects a final match, and another who verifies it. The result is sent back over the CJIS network to the submitting state, which records it and forwards it to the local police department—now the local authorities know whom they're booking.

In concert with building IAFIS, the bureau has undertaken to renovate its other massive electronic search service, the 32-year-old NCIC. NCIC already fields more than 600 million electronic inquiries a day on subjects ranging from stolen cars and boats to terrorists and escaped prisoners. In July, it plans to debut another service: instant single-fingerprint searches of a database of some 130,000 known fugitives and wanted felons. It is these quick-and-dirty searches, performed with mobile scanners linked to the onboard computers in patrol cars, that could save officers from fatal surprises in traffic stops.

These innovations are already drawing pre-release raves from top cops and longtime critics of the FBI's current ID system. IAFIS, integrated with the expanded NCIC, "will revolutionize police work," predicts Boston deputy police superintendent William Casey. "This will save the lives of police officers who aren't even born yet," crows Los Angeles' Bonino. But despite the ballyhoo, IAFIS won't arrive full-blown in July. Roberts says outside agencies won't be able to search latent prints against the FBI database until November or December. A digital repository of mug shots (to be captured at standard fingerprint stations) will also be phased in within six months of the launch, he says. Likewise, the FBI will phase in "expanded access to civil files"—though what that access will be is one of several big questions still pending.

Latent Issues

ANOTHER QUESTION: JUST WHOSE SEARCH SYSTEM IS THIS? IAFIS will be overwhelmingly weighted toward the ten-print searches that police and courts care most about—background checks run on prints taken from the people they stop, book and sentence. But it may not do as much for the smaller cohort of investigators trying to solve crimes with latent prints. Nowadays, detectives typically don't dust for prints after burglaries; their states' crime labs are too overloaded to trace them. If they expect a change under IAFIS, warns Ed German, the Army Crime Lab's senior special agent, "many police departments are going to be very surprised."

IAFIS promises to match only 635 latent crime-scene prints a day, even as it conducts 60,000-plus ten-print searches. This was no oversight, but a deliberate allocation of resources. The Advisory Policy Board urged against building a large latent-search capability into the national system because most such searches involve local offenders. And the 635 promised latent searches will consume much more computing power than all the ten-print searches combined. Because a ten-print's origins are known—say, "white female left index finger"—the search engine can concentrate on the pertinent section of its database. And because ten-prints are crisp and complete, it can compare them with the digital equivalent of a quick glance. Latent prints are often smudged and incomplete, with no indication of which fingers they represent, or the race or gender of the people who left them. And since each search can penetrate only about 30 percent of the IAFIS database, the system must make multiple searches to match a single latent.

Those 635 latent searches will seem even more meager when

Secret Handshakes

The FBI isn't the only federal security agency immersed in biometrics. With less fanfare (as befits its name), the Secret Service has led the nation, though not the world, into another brave new biometric realm: handwriting identification. Such identification is central to the service, whose work of protecting the president and other officials from would-be assassins begins with tracing threat letters. That effort received a big boost in the 1980s, when the German Bundeskriminalant (Criminal Police) developed an algorithm for plotting handwriting as arithmetic and geometric values. The Secret Service acquired the only English-language version of this "Forensic Information System for Handwriting" (FISH); Jim Grassman, who headed its Forensic Services Division from 1992 to 1997, says it has proven invaluable—and irreproducible. "Vendors would always call and say they had a better system," Grassman explains, "but it was all vaporware. No one could do it."

Under Grassman, the Secret Service lab expanded its FISH database to search nationwide for missing children. The service has also used it to assist the FBI, military investigators, the Capitol Police (tracing threats to members of Congress), and the State Department (with threats to diplomats). But Grassman longed to do more: "My big dream was to take FISH and do something similar to what the FBI is doing with IAFIS—to connect all local and state law enforcement agencies through a national network. My theory was that an individual threatening the president would start out threatening, say, the mayor, and work his way up."

But Grassman couldn't sell this dream where it counted: "It grew frustrating to go to the Treasury Department again and again trying to get money to solve crimes, when the bureaucrats weren't interested." He finally retired from the service and became strategic planning director for NEC's automated fingerprint program. Since then, however, the service has made some progress toward building a FISH network with terminals in major cities and other federal agencies. Meanwhile, the Bundeskriminalant is trying to trace identifying idiosyncrasies in typing; reading computer printers has proven more difficult than reading hands.

Nowadays, detectives typically don't dust for prints after burglaries. Those who expect a change under the FBI's new system will be sorely surprised.

apportioned among the nation's law-enforcement agencies. Most states will get only a handful of searches a day, and the army, navy and postal service will each get about 10 a day. "I have five labs," says David Larrabee, forensic sciences manager for the U.S. Postal Service's National Forensic Service. "We handle a number of bombings, drug cases, fraud cases, stolen money orders. We develop about 40,000 latent fingerprints a year. Ten a day is not enough."

Tom Hopper, chief of the FBI's CJIS Advanced Technologies Unit, says that the limit of 635 latent searches a day now appears overly cautious: "Our modeling looks like we'll be able to double that the day after we start up." If that's still not enough, he says, the FBI could always seek further funding for greater search capacity. But German and Larrabee note another IAFIS shortcoming: Only criminal files have been scanned for searching. Military, immigration, employment and other civil prints are warehoused.

Inaccessible civil files are not a big problem for police, who usually seek repeating criminals. But they might be for an organization hunting for an offender within its ranks—whose fingerprints will be held out of reach by the FBI. German, who conducts fingerprint searches for all branches of the military (but notes that he speaks only for himself and not for them) believes that searching military print files might resolve some of the hundreds of unsolved service crimes. Further, searchable military prints could help prevent corruption and stop ejected servicepeople from re-enlisting under other names.

New civil prints will be scanned in "from day one" of IAFIS, says Roberts, but kept separate from the criminal database for privacy reasons. As for scanning existing civil files, he says: "Not unless someone gives us the money." The FBI has already paid $32 million to scan 32 million criminal cards; it holds prints for about 40 million civil subjects.



COURTESY OF THE FBI

Inside the beltway: This mechanical relic once conveyed cards to fingerprint examiners.

Fingers to the Wind

AND SO, ON THE EVE OF ITS LONG-AWAITED DEBUT, THE WORLD'S largest computerized ID system is still a work in progress. Some backers and would-be users may be surprised and disappointed at its limitations. And questions of obsolescence already loom.

For instance, given the huge investment it's now making in fingerprint-based information technology, the bureau has to be watching a bit nervously as other biometric technologies ease into the picture. Higgins sees DNA matching and iris scans, and perhaps even facial recognition, as promising fingerprint alternatives. Bonino and German both urge that CJIS add automated palmprint searches, which are already used in Europe. "Half of all prints left at crime scenes are palms," notes Bonino.

Even if fingerprinting isn't replaced by these recognition techniques, the FBI's investment in large-scale, centralized data technology could be rapidly superseded by new computing techniques. German sees the emergence of what he calls "a new AFIS paradigm"—a decentralized identification network, somewhat like the Internet. In fact, the PC revolution is just now reaching the fingerprint field. Mainframe AFIS systems still run to hundreds of thousands of dollars. But last June the upstart Phoenix Group in Pittsburg, Kansas, began offering an "AFIX Tracker" that, according to its president, Derald Caudle, searches minutiae points in all latent/ten-print combinations, holds 30,000 print records (enough for a small city)—and operates on a Pentium II Windows machine with an 11.5-gigabyte hard drive. The price: $17,000 for the software, or $950 a month to rent the whole rig. German's Army lab took the first two.

German predicts the paradigm will really pop after this November, when the FBI will release Lockheed Martin's minutiae-extraction software into the public domain. "It'll be like phone-company deregulation. A lot of software companies will spring into AFIS." Where only about 600 larger cities and agencies now have it, individual police precincts will get their own, German believes. Initially, at least, that should create much more demand for the FBI's IAFIS, as the hub of a fast-expanding network. But what about when all those little AFISes learn to swap prints and searches directly, on the Internet search-engine model?

As prices drop, German foresees, "You could build your own AFIS." Imagine. Instead of tracking each other down by name via Hotbot or AltaVista, we'll trace each other's fingerprints. Who was that woman at the party last night? Pull a print off her wineglass. In the near future, thanks to new technology, look for gloves to become very, very fashionable. TR

■ The founders of Cambridge Display Technology, a U.K. startup, believe they can make light-emitting plastics part of everything from video wristwatches to flexible TV screens. And they just may be right.

Displaying a Winning Glow

BY MICHAEL KENWARD

PHOTOGRAPHS BY ROBERT WALLIS

JEREMY BURROUGHES LOVES SHOWING OFF THE week's newest color. The current special is a shocking pink. Just the sort of thing a toy maker could use to appeal to young girls, he muses. But this is no ordinary fashion statement. Burroughes, director of technical development at Cambridge Display Technology (CDT), is holding a glowing piece of plastic plugged into a bank of electronic equipment.

The pink glow comes from one of the hundreds of minuscule light-emitting diodes (LEDs) that Burroughes and his colleagues are testing in a back room of CDT's labs in the outskirts of Cambridge, England. There, surrounded by Cambridge University and crammed into a small office building that it shares with three other high-tech companies, CDT is putting plastic LEDs through their paces, testing not just new colors but also how efficiently the devices turn electricity into light and how long they last before the light fades—crucial parameters that will determine the commercial viability of these remarkable new materials, which are known in the trade as light-emitting polymers, or LEPs.

The ambition of CDT is no less than to turn these glowing plastics into products that will revolutionize computers and TV displays, as well as toys, billboards and just about any other object that you could make out of a piece of plastic that gives off light. That ambition may be feasible because LEPs have dramatic advantages over current display technologies. And despite the university-like setting of the company, CDT's effort is no academic pipe dream.

The company is part of what is becoming known in Europe as "the Cambridge phenomenon," a flurry of spinouts based on technology developed at Cambridge University, one of England's most prestigious institutions. This ancient seat of learning, in the flat and inaccessible east of England, has given birth to a cluster of high-tech companies that rival those in the city's North American namesake. And among these young darlings of British entrepreneurs, CDT, which numbers among its founders some of the early pioneers in the development of LEPs, is a rising star.



Watching the future: Jeremy Burroughes tests a prototype plastic TV screen.

Plastic TVs

EARLY LAST YEAR, THE COMPANY GRABBED headlines around the world when it unveiled a working TV screen that measured only 50 millimeters square and only 2 millimeters thick. The device is just a crude prototype but is meant to demonstrate a replacement for the bulky bottles behind most TVs. It was jointly developed with the Japanese electronics giant Seiko-Epson, and the companies billed it as the world's first plastic television screen. It used a simple monochromatic display and showed the British cartoon characters Wallace and Gromit in a sickly shade of green. But CDT and Seiko-Epson promise soon to show off the first full-size color display using light-emitting polymers.

The glowing polymers are gunning to become a factor in the worldwide race to commercialize technologies for flat-panel displays—thin screens that, in one projected use, could be used in a TV that hangs on the wall. For all their success in making flat screens for portable computers, technologies such as liquid-crystal and plasma displays have yet to displace the clunky cathode ray tube from the desktops of the world, let alone the living rooms. Meanwhile, newer technologies, such as field-emission devices—which essentially rely on miniaturized versions of the electron guns used in cathode ray tubes—have proven expensive to make. That leaves a big opening for the light-emitting plastics. If they can be made to work.

A commercial TV with a plastic screen is still several years down the road. In the short term, CDT and its partners plan to market LEPs for the displays in mobile telephones or the simple indicators used in such products as appliances and CD players. That's now largely the domain of liquid-crystal displays and LEDs, and it's a roughly $2.5-billion-a-year business. As *TR* went to press, Philips Electronics, which licensed the rights to CDT's technology in 1996, was scheduled to begin test-manufacturing LEPs for these uses.

The potential has made light-emitting plastics one of the hottest areas of materials research, drawing the attention of electronics and polymer makers around the world. While it's doubtful that any one



Friendly embrace: The science of Richard Friend has made CDT a market leader.

company will dominate the business, CDT has used its strong patent position and a clever business strategy to ensure its technology plays a key role. Even more remarkable, the 33-employee startup has outcompeted some of the world's largest materials science research groups in doing so.

Light-emitting plastics are so appealing in electronic applications because they can be used to make LEDs whose active ingredient is a tiny diode made of a polymer rather than crystals of gallium arsenide or the other inorganic materials used in conventional LEDs. Polymers can be chemically tailored to produce light of any wavelength that you care to mention; in contrast, it can be difficult to adjust the colors emitted from inorganic semiconductor crystals and some hues are particularly elusive. Polymers are also far easier to manufacture and process than the inorganic semiconductors used in current LED displays.

A further attraction of LEPs is that, unlike the liquid-crystal displays used in many laptop computers, you can view them from any angle—as anyone who has used a laptop knows, you have to stare it straight in the face to see its contents properly. What's more, LEPs avoid the streaking, or ghosting, of images that plagues flat-panel displays using liquid crystals, because the tiny plastic light emitters can switch on and off extremely rapidly. In contrast, liquid crystals often do not respond quickly enough to keep up with the image as it flashes across the screen.

But the streaking isn't the most serious obstacle posed by the current technologies. Liquid-crystal displays must be sandwiched between two layers of glass; and, since they don't create light themselves, there must be a light-emitting layer behind them. What has really captured the imagination of electronics producers is that LEPs can be put down as thin films on various substrates, including other plastics. That means you could coat a cheap, flexible sheet of plastic with a thin layer of LEPs. The potential products are almost endless: from a glowing Barbie doll to screens that can be rolled up and stored to permanent, rapidly changing signs that could be put up like wallpaper.

That's the promise. The reality is that commercializing new electronic materials is a fickle and expensive process. It takes time—and manufacturing clout. It is for precisely these reasons that CDT has hedged its bets by forming alliances with several leading manufacturers. Leveraging the strength of its fundamental science and patent portfolio, CDT has wooed many of the industry's largest corporate players, becoming a technology partner with the likes of Philips Electronics, Seiko-Epson, DuPont and the giant German plastics maker Hoechst.

> Like many other startups, CDT initially bit off far more than it could ever hope to chew.

Almost Fatal

CAMBRIDGE DISPLAY TECHNOLOGY MAY have hit on a winning market strategy, but it wasn't always so. From the beginning, few questioned its scientific credentials. Its founders, after all, are credited with the key discovery that made LEPs possible. But like numerous other startups spun off from university research labs, CDT in its early days displayed an almost textbook case of how not to succeed, wandering away from its strengths and biting off more than it could ever chew. The company formed in 1992, adopting an almost fatal business strategy—aiming to become both a manufacturer and marketer of materials and displays.

Today, after an about-face, the company has returned to a specialized niche that seems to suit it better: technology development. It will leave the production of LEPs to its materials manufacturing partners, while its electronics partners incorporate the materials into devices.

A steady stream of corporate visitors to the company's labs is a ringing endorsement of that strategy. Far from Cambridge's fashionable science park, a quarter of a mile down a bumpy lane that is all too easily missed, CDT operates in buildings rented from Cambridge University. On one side are labs where academic researchers study earth sciences; on the other side is a definitely unfashionable field of cows.

CEO Danny Chapchal says that CDT is looking for larger premises, but it won't move far. He wants to stay near the company's intellectual roots—Cambridge's Cavendish Laboratory, one of the world's most famous physics labs. It is there that a research team headed by Richard Friend—now an executive director of CDT and the company's R&D director, as well as Cavendish Professor of Physics at Cambridge University—made the first plastic LEDs in 1989; it's also where Friend, Burroughes and their colleagues put the company together.

Plastic's debut as a light-emitting material with true commercial promise almost went unnoticed. At the time, Burroughes was working for his PhD in the Cavendish Laboratory as part of Friend's research group. "There's this rumor that it was a darkened room," recalls Burroughes. In actuality, he says, "it was a fully lighted room because I was busy setting up another experiment. I looked across the room and there it was, glowing away."

The company's scientist-founders had

Polymer Partners

COMPANY	TERMS	OBJECTIVE
DuPont (March 1998)	Two-year joint development agreement.	Supply LEPs to electronic makers.
Seiko-Epson (Feb. 1998)	Joint development agreement to combine LEPs with active matrix display technology.	Market full-size color displays for computers and TVs.
Hoechst (May 1997)	Hoechst pays up-front fee for access to CDT's patents.	Hoechst to provide LEPs to electronic customers.
Philips Electronics (Sept. 1996)	Philips pays license fee and royalty on any LEP products.	Philips to initally market backlights for LCDs and displays for consumer products.

SOURCE: CAMBRIDGE DISPLAY TECHNOLOGY

their commercial antennae tuned from the beginning. Even before they published the results in *Nature* in October 1990, they had filed a patent. In Britain, this is rarely the first thought when presented with groundbreaking science, and there was no mechanism for the university to fund patent filings. So the researchers paid for the patent out of their own pockets. Burroughes, Friend and Donal Bradley, another member of the team, each chipped in £350 (almost $600 at today's exchange rates) to fund the preliminary filing. That patent, supported by a raft of later patent filings, became the cornerstone of CDT.

Although it might have seemed a hardship that the researchers had to pay for the costs of filing their own patents, in fact it turned out to be a lucky break. The scientists formed the company to pay the continuing costs of the patent process. The university handed over its patent rights to CDT in return for a share of the company, and the scientists set out to raise funds using the patents as collateral. It was not until 1994 that the company began to operate in earnest.

At that time, Friend's links with CDT had diminished. He wasn't exactly pushed out, he insists, but the company needed to avoid being seen as just an appendage of his research group. Burroughes was also on the sidelines by then. He had spent the summer of 1991 making "the first polymer display of any sort." Building this simple display "was quite fun," he remembers, but he soon started work at the Toshiba Cambridge Research Centre. While he helped to recruit staff for CDT, he was reluctant to become more closely involved. "I didn't think that the way that the company was being set up was right at the time," he says. "It was very naive."

The problem was that CDT had the entire world in its sights. It was going to build factories to make LEPs and electronic displays. The only drawback was that scaling up the technology could take millions, while the costs of building electronic manufacturing plants can easily run into billions of dollars.

A Bright Idea

IT WAS SEVERAL YEARS BEFORE CDT started to go in a direction that appealed to Burroughes. That was in March 1996, when Danny Chapchal came on board. Chapchal, in his 50s and trained as an accountant, had a track record of, as he puts it, "turning around sick companies in the software business." But, he recounts, "within about three days of arriving, I thought that I must be mad. These are people with a great idea who are hell-bent on suicide and certainly don't want managing." It was the company's completely unworkable business plan that upset him, especially when he was asked to put his name to it. This called for CDT first to raise $6.5 million, followed by a further $11.5 million, with the idea of manufacturing displays and flat screens. "That was a recipe for suicide," says Chapchal.

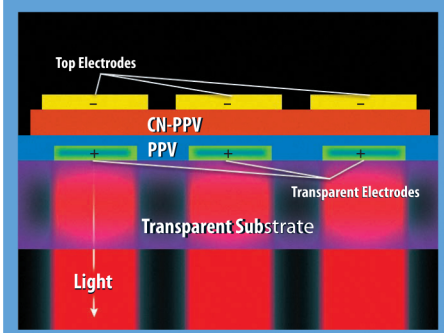
His answer was to turn CDT into a licensing company. It would develop its own science and technology, and enter into partnerships with large companies that had the money needed to create a new industrial infrastructure. In a business model that has become common in the biotech sector, CDT would share intellectual property rights in a number of joint development efforts.

Chapchal's strategy quickly paid off *(see "Polymer Partners," p. 71)*. The first breakthrough was a licensing deal with Philips. "We had only a few months' money left. We went to Philips for two reasons," explains Chapchal. "They had lodged an opposition to the patent, so we knew that they were interested. And we

A Thousand Points of Light

Plastics are the familiar stuff of buckets, garbage bags and garden furniture. But by tinkering with the molecular structure of polymers, chemists and physicists are also looking to turn it into the stuff of electronics, from vivid graphics displays to flexible transistors.

Electrically conducting polymers have been around since the late 1970s, but it was the 1989 discovery at Cambridge University's Cavendish Laboratory that a material called poly(*p*-phenylene vinylene), or PPV, was electroluminescent that set the world of information displays alight. It turns out that PPV glows when the material is layered between a pair of electrodes with a current passing between them. For certain conventional inorganic semiconductors that would be normal; for a piece of plastic it was unheard of.



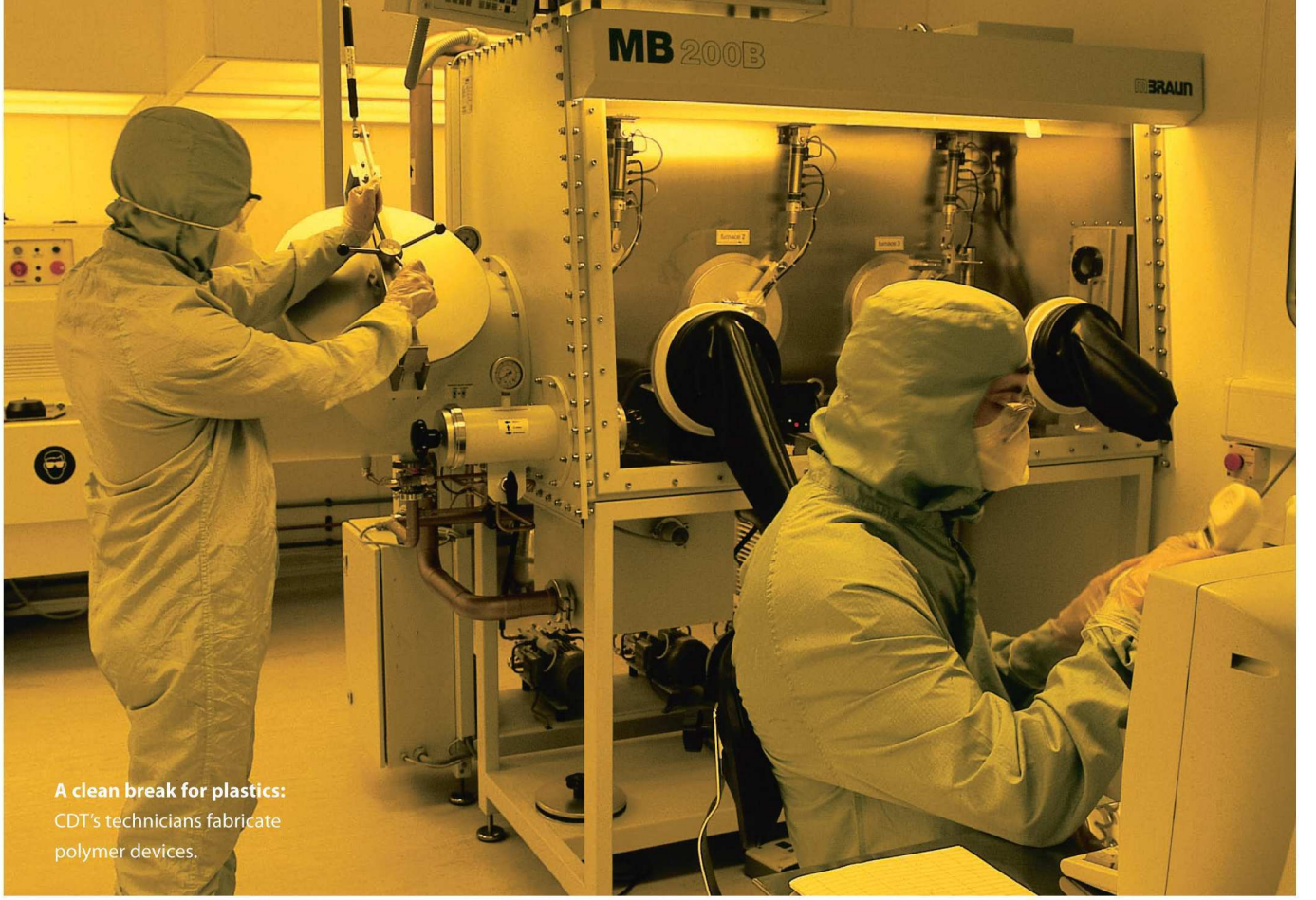
BETSY HAYES; SOURCE: CAMBRIDGE DISPLAY TECHNOLOGY

Glowing potential: CDT uses two thin layers of different polymers (PPV and CN-PPV) to increase the light-emitting efficiency of a monochromatic display. Negative charges are injected from the top electrode (the cathode), while positive charges come from the transparent electrode (the anode); where the charges meet, the polymers emit light.

PPV gives off light because it is a "conjugated polymer." These materials are characterized by double bonds alternating with single bonds in their carbon backbone. This arrangement produces an overlap in electron orbitals and a "sharing" of electrons. That, in turn, allows an electronic flow along the carbon chain, creating a material that can act either as a conductor or a semiconductor.

To make a polymer light-emitting diode (LED), scientists construct a plastic sandwich of very thin layers of fluorescent polymer between two electrodes. Connecting the electrodes to a battery forces electrons and their negative charge into the semiconducting polymer from a metallic cathode on one side, while an anode injects "holes" of positive charge from the other. When the charges meet, they annihilate one another, producing a photon. The result is that the polymer fluoresces.

Emitting light is just one of the potential electronic properties of plastics. Several research groups, including those at Philips Electronics, Lucent Technologies' Bell Labs and Cavendish Laboratory, have also formulated transistors out of polymers. And last summer, Bell Labs, and Richard Friend and co-workers at Cavendish, separately reported combining polymer transistors and display components. Previously, the need to use inorganic transistors with light-emitting polymers had partially negated some of the advantages of the plastics, namely their flexibility and thinness. By shedding their dependence on inorganic transistors to power the points of light, LEPs may finally shine in all their plastic glory.



A clean break for plastics: CDT's technicians fabricate polymer devices.

knew that they had a team working on it." The agreement with Philips, in September 1996, did three things for CDT, says Chapchal. It gave the company "a little bit of money that we desperately needed. When I arrived we had six months of money." The Philips license also ended the electronics giant's challenge to CDT's patent. Perhaps most important, "we got publicity like you would not believe," says Chapchal. "Within days, we had people banging on our doors saying 'Can we invest?'"

A second patent dispute was settled when the company signed a licensing deal with Uniax, another LEP startup based on technology developed at the University of California, Santa Barbara. With no outstanding challenges to its original patent, CDT had an asset that could be worth millions. "One of the things we have turned out to be good at," says Friend, "is patent writing." The core patent covers a series of claims and is, he says, "a bit like having a patent on silicon."

Sink or Swim

IN A MOVE TO STRENGTHEN ITS SCIENCE, CDT renewed Friend's relationship with the company. In April 1997, Friend became an executive board member and R&D director. As Chapchal describes it: "I said to him, you are claiming all the credit for inventing this thing, so now you are going to nail your flag to the mast and sink or swim by it."

Chapchal also coaxed in a new round of investors. A group of entrepreneurs headed by Lord Young of Graffham, formerly chairman of the British telecommunications company Cable & Wireless and secretary of state for Trade and Industry in the British government, agreed to invest up to $7.5 million over four years. This was, says Chapchal, "one of the best deals I have ever done." He is particularly pleased about the long-term nature of the investment. "I was acutely aware that no matter how good I am at managing, I have got a bunch of 'techies' who want to spend money. If I had that amount of money in one year it would all go."

> The CDT patent could be worth millions—it's a bit like having a patent on silicon.

Having refocused on technology development, CDT has made rapid progress. The company has now covered the spectrum with its LEPs. As well as the red, green and blue emitters that are essential for full-color images, CDT has created a palette of other colors. "There are a lot of monochrome applications that people want," says Burroughes. For example, toy makers and companies wishing to display their corporate image in lights might be candidates for proprietary colors.

It isn't just the technology that is racing ahead. The science proceeds in leaps and bounds, producing results that sometimes seem too good to be true. "I never thought we would get this good," enthuses Friend. Indeed, the latest materials appear to be more efficient in emitting light than theory allows. This provides plenty of science to delight the academic scientists back at Cavendish Laboratory. Says Friend: "I never thought I would have such fun with it."

If CDT is successful, those playing with glowing plastic toys and bendable display screens might eventually be mouthing the same sentiments. ◊



Ideas are like Children

They used to call him crazy. Now they call him smart. Chemical engineer Robert Langer crafts cures from plastic.

Q & A

There was a time when medicine and chemical engineering hadn't been properly introduced. Then Robert Langer crashed the party.

That was in 1974, when Langer, now Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering at MIT, signed on as a postdoc in Judah Folkman's cancer lab at Boston's Children's Hospital. Mingling with the surgeons and scientists, the young chemical engineer was far afield. Far enough, in fact, to discover his uncommon calling: molding materials that turn biological discoveries into medical cures.

Synthetic polymers are Langer's specialty. He crafts, from plastic, implantable dispensing machines for some of biotechnology's most esoteric therapies, as well as safer delivery devices for more conventional medicines. Langer's work is one of the pillars of the multibillion-dollar drug-delivery industry. But the pace of his progress is such (his name appears on more than 330 patents) that he has populated not one, but two new industries with ideas and students. Langer's second sphere of innovation is tissue engineering, an emerging discipline in which his synthetic polymers are helping researchers grow replacement body parts in the laboratory.

In his award-cluttered MIT office, Langer spoke with Technology Review Associate Editor Antonio Regalado.

TR: Biomaterials are the common thread in your work. What are they, and why are they important?

LANGER: A biomaterial is any substance other than food or drugs contained in a therapeutic system that's in contact with biological tissues or fluids. Biomaterials have been around for a while—more than 2,000 years in the case of dental fillings. Pound for pound, fillings are the

PHOTOGRAPHS BY DAVID ZADIG

most common biomaterial in use. Newer applications of biomaterials in drug delivery and tissue engineering are important because they have the potential to revolutionize certain medical treatments.

TR: How have doctors chosen which materials to use?
LANGER: There's some interesting history there. Until the 1970s physicians tended to adapt off-the-shelf materials designed for consumer applications. For example, a polymer called polyether urethane used in artificial hearts was originally used to make women's girdles. Dialysis tubing was originally sausage casing. And breast implants, one of them was actually a lubricant and the other was a mattress stuffing. They just used any material they could find that resembled the tissues they were trying to replace.

But the off-the-shelf approach has led to a number of problems. For instance, when blood hits the surface of an artificial heart, clots may form and the patient may suffer a stroke.

TR: Weren't chemical engineers or materials scientists involved in choosing which materials to use?
LANGER: Well, not very much. So at the very beginning of my career, I proposed a different approach to designing biomaterials, which was to ask "What do you really want in a biomaterial from an engineering, chemistry and biological standpoint?" and then synthesize it from first principles.

TR: At the time, was there any precedent for taking that kind of approach?
LANGER: Not really. And I can tell you that when I started out, this was very odd work for a chemical engineer to be doing, since it wasn't mathematical modeling or something to do with the oil or chemical industries.

TR: What types of problems can better biomaterials solve?
LANGER: There are many applications, from pacemakers to contact lenses, but I have worked mainly on solving problems related to drug delivery. The things you'd like to do are keep drug levels within a certain range, target drugs to a particular cell type or tissue, or help out with drugs that don't last long in the body, like peptides or proteins. It's an important area, since up to 100,000 deaths a year in the United States each year can be attributed to adverse drug events, such as an overdose. For instance, I have synthesized polymers shaped to trap or encapsulate drugs, then release them at a precise rate.

TR: What are the engineering challenges in using polymers for drug delivery?
LANGER: It starts with an engineering design approach. For example, in the area of degradable synthetic polymers we are remarkably limited in terms of what we can put in the human body. For many years, the only degradable materials available were some synthetic polyesters used in sutures. But these get spongy and ultimately fall apart. If you put a drug into that kind of polymer, that could lead to a burst of drug release. That could be fatal with a potent drug like insulin.

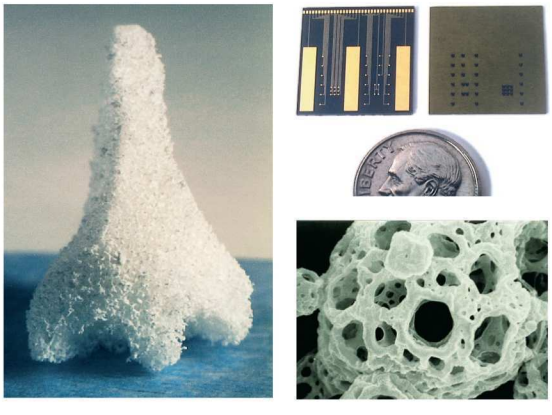
What you'd really like to do is design a system that would erode, in much the same way a bar of soap dissolves. Along with my students, I went through an entire engineering analysis to determine how one would do this, and came up with a family of polymers that we call polyanhydrides.

TR: So you solved the engineering question, but are there applications for these polymers?
LANGER: A surgeon at Johns Hopkins named Henry Brem came to me about using these polymers in a new brain cancer treatment. There were many scientists who doubted us. They said we wouldn't be able to synthesize these polymers. When we did, they said that the polymer would be toxic and that it couldn't be manufactured.

Today as a consequence of studies done by us and others, polyanhydride matrices are used to deliver a powerful chemotherapy called BCNU to treat brain cancer. Normally, BCNU is delivered through the blood, and it is very toxic to the liver, kidneys, and spleen. In this case, the surgeon removes as much of the tumor as possible, but also places up to eight small polymer-drug wafers at the tumor site. The drug is slowly released from the polymer for one month to kill remaining tumor cells and harmful side effects are minimized. One recent clinical trial showed that after two years, 31 percent of the treated patients were alive whereas only 6 percent in the control group survived. This was the first new brain cancer therapy approved by the Food and Drug Administration in more than 20 years.

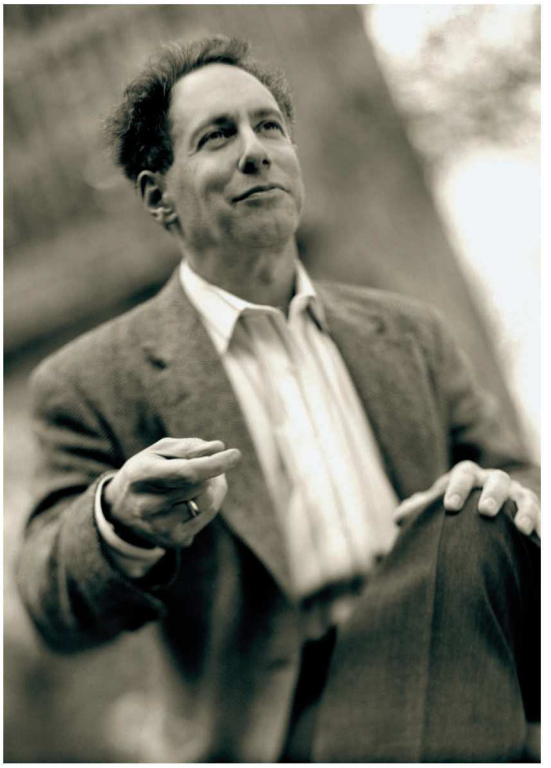
TR: What are the major technical trends in biomaterials for drug delivery?
LANGER: One area my lab is working in is designing polymer nanoparticles to deliver DNA efficiently in gene therapy. This is basically a tiny polymer sphere with DNA inside that you want to get into a cell. It's very challenging, but the plus is that you may get some significant safety advantages over the gene-delivery systems that are now in clinical trials, which make use of viruses.

Further out, we're thinking about things like "smart" systems that can deliver drugs in response to specific body signals. You could have an implantable biosensor that can detect glucose levels and tells a drug-delivery implant to release insulin when it is needed.



Inventor's gallery: *(clockwise from left)* Synthetic nose for growing cartilage, drug-delivery chip and microsphere.

TR: What about permanent implants?
LANGER: A lot of people think the ultimate solution will be smart systems that behave a lot like the part of the body you are trying to replace. With artificial blood vessels, we are thinking now about approaches where you could attach molecules that might be desirable, say, something to attract endothelial cells [the cells that line normal blood vessels] and help create a natural lining. In a sense, I think what you want to do is get rid of materials—you want them



to do their job and then disappear, or become invisible.

TR: You're talking about combining synthetic materials with proteins or cells?
LANGER: Right. The merger of engineering and biology is very important today. There is a real revolution going on in the biological sciences, and the associated engineering opportunities are enormous. In a field like tissue engineering, it's the integration of knowledge from cell biology, materials science and process science that you need to create a new tissue.

TR: You mentioned tissue engineering. Can you explain what this field is about?
LANGER: The approaches that we use start from the observation that if you take cells and inject them into the body at random, nothing happens. But if you take those same cells and line them up close enough together, they can form tissue structures. If you take mammary epithelial cells and line them up, they will organize and make milk.

The first engineered tissue was skin, which you can grow on a two-dimensional surface. But in 1986, along with Jay Vacanti [a pediatric surgeon at Massachusetts General Hospital], I decided that if you really wanted to make tissues—bone, cartilage, liver, you name it—you could use synthetic polymers and put them into three-dimensional structures. That provides a template for the cells to grow and allows them to reform structures.

TR: What kinds of tissues are you making in your lab?
LANGER: We are trying to make cartilage by growing cartilage cells on degradable polymer foams. We can design the foam in the shape of a human nose, for example, then place cells throughout the foam and grow it in a bioreactor. Over time, the cells produce extracellular matrix which provides strength, and the polymer dissolves. The result is pure cartilage in the shape of a human nose.

TR: Has this kind of work progressed outside of the lab?
LANGER: This field is growing pretty fast. Several tissue-engineered skins are approved by the FDA [for treating burns or wounds]. Cartilage is in clinical trials, and liver is in clinical trials [a device for liver-failure patients in which blood is passed outside the body through a cartridge filled with liver cells]. So there are a number of things that have moved out of the laboratory. And before that, in animals, there are probably about 20 tissues being worked on, including heart valves, blood vessels and intestine. All of these are grown on polymer scaffolds.

TR: Will we be able to regrow very complex organs, like hearts?
LANGER: I am sure with enough time, perhaps decades, all these things will be figured out. But right now, it's very difficult. It really depends on the complexity of the tissue, and our understanding of the biology and engineering challenges, and also how perfect you need the system to be. Though the FDA has approved tissue-engineered skins, those are not absolutely perfect skins—they're just better than anything else you can do. And there are cell types, like nerves, that have proven to be really complicated. We are just starting to learn things from biology that are enabling us to do a little bit better in this area.

TR: More than 50 companies have licensed your inventions in polymer chemistry. How does it feel to help create new industries?
LANGER: It feels good. My goal has always been not just to write the scientific paper or file a patent, but to really push some of these ideas to the point where they will affect people's lives in a positive way. And it takes a long, long time for the most part. When you start doing these things, no one believes in them, nobody wants to fund them, and companies don't want to do them. And you get criticized a lot.

The important thing to remember is it's not going to be by the efforts of one person or one lab that these problems get solved. What makes these approaches work is ultimately having hundreds or thousands of people working on them. And that is what has happened in drug delivery, and that is what is starting to happen in tissue engineering and bioengineering in general.

TR: What does the future hold for you?
LANGER: The big thing for me is to keep coming up with these early-stage ideas, which people may call crazy as they called some of the other ideas crazy 10 or 15 years ago. For instance, we're working on implantable microchips that can release specific drugs or vaccines into the body on demand by telemetry. One of my graduate students, John Santini, is building a drug-delivery chip with 1,400 reservoirs, in which you could put 1,400 different substances, or many doses of one drug. You'd probably put a little microprocessor on it and signal it from the outside. I want to move this far enough along so that, again, we'll end up seeing a lot of people working on it. For me, ideas are like children growing up. I want to nurture them so they are stable and so they will happen. ◊

"There is a real revolution going on in the biological sciences, and the associated engineering opportunities are enormous."

Science Triumphs, Market Fails

ROTAVIRUS IS A UBIQUITOUS, EQUAL-OPPORTUNITY pathogen that infects rich children and poor, the hygienically correct and the unspeakably filthy alike. The vast majority of the 130 million children born each year in the world feel its gastrointestinal bite.

The good news is that the Food and Drug Administration recently licensed Wyeth-Ayerst Laboratories to market an oral vaccine against rotavirus in the United States, where the disease results in about 50,000 hospitalizations and perhaps 40 deaths a year. The bad news is that the vaccine may not be available for many years in the developing world, where the severe diarrhea and dehydration that accompany infection claim somewhere between 600,000 and 800,000 young lives a year.

When I asked Roy Widdus, scientific director of the Geneva-based Children's Vaccine Initiative, how Wyeth-Ayerst's initial price of $38 a dose—or a little more than $100 for a full course of treatment—would play in the developing world, he paused, no doubt wondering if he were being interviewed by an idiot. "It's a nonstarter," said Widdus with a grim laugh.

To have an effective childhood vaccine and withhold its use does indeed, in the idiom of the Hippocratic oath, do harm.



Make no mistake, this column isn't an exercise in company-bashing. Wyeth-Ayerst officials, in addition to providing free vaccine for field trials, have on numerous occasions stated their intent to make this vaccine widely available as soon as possible, and a number of interested parties—including the Children's Vaccine Initiative, the World Health Organization, UNICEF, the Centers for Disease Control and Prevention, the World Bank and the Rockefeller Foundation—are struggling to help them do it. But they are all up against market forces every bit as ruthless, dispassionate and opportunistic as the virus itself.

Almost since 1973, when the first rotavirus was discovered in Australia, a team of researchers at the National Institute of Allergy and Infectious Diseases led by Albert Z. Kapikian has toiled to concoct a vaccine. Kapikian's group ultimately developed what he calls a "modified Jennerian vaccine." Just as Englishman Edward Jenner created a vaccine against smallpox in the 18th century by inoculating humans with the related but milder cowpox (or vaccinia) virus, Kapikian's team realized that infection with a milder rotavirus common to rhesus monkeys induces immunity in humans to one of the prevalent strains of rotavirus. Since there are four principal strains of the virus in the world today, Kapikian's team cleverly engineered the monkey viruses to display the surface of the four major human strains.

We already know the vaccine works in a low-income setting. It provided 88 percent protection against diarrhea and 75 percent protection against dehydration, the most severe and life-threatening symptoms of rotavirus, in a study of more than 2,000 Venezuelan children. But the profitable markets lie in the United States and Europe. Wyeth-Ayerst has applied for a license in Europe, but not yet in Venezuela, even though a company spokesman referred to the trial there as "pivotal."

All isn't necessarily lost for the children of the poor countries, though, since everyone assumes something called "tiered pricing" will come into play. Once the manufacturer increases production efficiencies, reduces production costs and begins to see some revenues, the argument goes, it can begin to offer the vaccine at a much discounted price. Widdus cites two examples. In 1986, a recombinant hepatitis B vaccine became available in the United States at more than $30 a dose; it took 12 years for "any significant drop in price," according to Widdus. The initial price for *Haemophilus influenzae* type b vaccine, introduced around 1990, was more than $20; it took eight years for the dose to drop to around $1 or $2. "With rotavirus," Widdus says, "we hope that we'll see some significant price tiering within five years."

To be sure, compelling scientific questions remain about widespread use of the vaccine. There is a question of whether higher doses may be necessary in situations of poor hygiene and minimal infrastructure in the developing world. And field tests are already under way to see whether the preparation works in India and Bangladesh. "The further you get from the industrial world setting," Widdus says, "the likelier it is that you'll encounter strains that are not part of the vaccine."

There is no easy solution—but there is also no reason to feel comfortable with the status quo. The market forces currently in place impose the cruelest sort of medical triage on the global population—indeed, upon the most helpless portion of that population, in this case infants and children. No one expects Wyeth-Ayerst to underwrite accelerated testing and distribution; shareholders wouldn't stand for it, and the company is already looking over its shoulder at several competing vaccines in development. The NIH invested considerable resources developing the vaccine, but has no mechanism for providing bridge funding that might initiate field tests sooner in developing countries. WHO, UNICEF and AID all are committed to expediting the process, but no agency is rushing to write a check that might ultimately add up to $50 million.

So while the free market runs its course, the lives of perhaps 2 million children may be lost over five years. At some point we have to look closely at the moral ramifications of economic imperatives: To have an effective medicine and withhold its use does indeed, in the Hippocratic idiom, do harm. ◊

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JAMES STEINBERG

VIEWPOINT | BY DANIEL AKST

Ludd's Choosy Children

TV good, microwave bad. Now, why is that?

MARRYING YOUR DENTIST, AS I DID, means learning all sorts of things you never imagined you'd know. Some of them are even useful. Smoking, for instance, will make your teeth fall out, and raisins can be harder on the old choppers than chocolates. But the biggest lesson has to do with technology. What I've learned about this from being around my wife is that there are no Luddites with toothaches.

The Luddites, you'll recall, were disaffected craftsmen who destroyed newfangled textile machinery in England in the early 19th century. Today lots of people fear technology, or at least new technology, and a certain amount of Luddism is probably inevitable in a time of rapid change. But what's striking, as people cope with all of this, is how irrational we can be when confronted with everyday technologies we don't understand. Los Angeles, where my wife practiced dentistry, is a showcase for the phenomenon of "selective Luddism": a big, sophisticated city that hasn't fluoridated its water. My wife's patients there included plenty of people who were open to almost any new idea, yet were deeply suspicious of modern medicine and technology—except, of course, when they had a toothache, at which point they were happy to embrace any substance or technology that brought them relief. I remember much wariness about silver fillings, but hardly a peep about lidocaine.

Some of this is understandable. With its sunshine and smog, caressing breezes and crime, there is a quality of paradise lost about Los Angeles that can make anyone leery of progress. Yet human responses to civilization's discontents are frustratingly inconsistent. Our friends in L.A. wear machine-made clothing and drive cutting-edge cars through a web of sophisticated traffic signals, architecture and engineering to reach health-food stores where they escape modern farming technologies by "buying organic."

When my wife was carrying our twins, we encountered pregnant women who insisted on natural childbirth—in a high-tech medical center, of course. I confess to being puzzled. Advocates of natural childbirth don't walk barefoot to the hospital, after all, and they bring the new baby home to a house with indoor plumbing and central heat. They don't stop buying shampoo or sending e-mail, either, and they have countless sonograms en route to delivery. So why the desire to experience "natural" childbirth?

I think "experience" is the operative concept here, backed by a general desire to be free of what we perceive as the dangers of technology at such a sensitive moment. We remember at such times that medical science brought the world thalidomide, but we remember also how useful blood tests, amniocentesis and the like can be in helping safeguard mothers and fetuses. So we're torn. To borrow an adage from Madison Avenue, we think half of all the money spent on technology is wasted. The question is, which half?

The classic example, of course, is flying. You are probably safer on a major U.S. airline than in your bathtub, yet my mother-in-law (who smokes cigarettes) is still somewhat afraid to fly. Who understands, after all, what keeps airplanes aloft? Who was this guy Bernoulli anyway? Microwave ovens, despite their well-established harmlessness, are also a focal point for outbreaks of selective Luddism. A friend in Santa Monica won't own one, even though she uses a computer every day, commutes to work by car, and casually flies coast to coast.

What accounts for all this selective Luddism? My friend's phobia points to a possible explanation, which is that people's willingness to embrace a new technology is in inverse proportion to its invisibility. Sensitized by stories of the harm caused by chemicals and radiation, people are nervous about microwave ovens, cellular telephones and other mysterious electronic devices. Thus food irradiation, which would save many lives annually, remains largely taboo. That so many of these modern technologies are simply beyond the average person's understanding only enhances people's fears. (A kind of technological grandfather clause seems to exempt television and radio transmissions, which are also invisible—perhaps because they became commonplace in the days when people still thought radiation was fun. Remember, there was a time when children routinely put their feet into X-ray machines...in shoe stores.)

Yet safety can't be the main issue. The automobile, for instance, is a very risky technology indeed. Each year auto accidents kill more than 40,000 Americans and injure 3.5 million others. Not only that, the internal combustion engine gives off air pollution that kills thousands and plays a major role in the accelerating warming of the planet. Driving everywhere also makes people fat, which further contributes to health problems. Yet my mother-in-law doesn't hesitate to get into her Volvo, as long as she doesn't have to drive it to the airport to catch a plane.

To borrow an adage from Madison Avenue, we think half of all the money spent on technology is wasted. But which half?

The case of the car suggests a second possible explanation for selective Luddism: If a technology offers irresistible personal benefits, we will embrace it regardless of the risks. In this sense, the selectivity is rational, since people have decided that the freedom, time-savings and other advantages of auto ownership outweigh the many disadvantages of driving.

But what about high-tension wires? Universal electrification brings very tangible benefits, after all. Here, however, the Problem of the Commons arises, except in reverse. Instead of individual benefit and socialized cost, we have socialized benefit and at least the perception of individual cost. Therefore, we reject the perceived risk of living near high-tension wires even when we understand that somebody's got to do it. Selective Luddism makes at least a superficial kind of sense here too.

Nevertheless, selective Luddism is not the result of any sophisticated calculus of risks, as is evident at your neighborhood McDonald's. Modern fast food establishments sell food that is unmistakably a product of technology. It's also usually filled with fat, salt and calories, which doesn't stop millions of Americans from gorging on it daily. It's hard to believe people think the benefits of greasy gray hamburgers outweigh the risk of heart disease. But the threat of fast food is visible, the technology is easy to understand, and the likelihood of harm is far in the future. This points to yet another possible explanatory principle of selective Luddism, which is that people seem to fear a low probability of immediate harm much more than a high probability of harm some day in the hazy and far-off future. That's why people still buy cigarettes.

The selectivity of Luddism also seems to vary with social class. In most of the country, for instance, vinyl windows and siding make sense, and because of their affordability are embraced by people who don't have a lot of money. On the other hand, these products are regarded by the well-to-do as hopelessly tacky—perhaps, as the sociologist Thorstein Veblen suggested with his theory of conspicuous consumption, precisely because they are so practical and cheap. Wood, which is torn from the forest and requires constant care on a house, remains much more socially acceptable among those who look down on the working class.

Class-based aesthetics, in fact, seems to play a role in many of the decisions people make about technology. Perhaps this is why professional ballerinas shun high-tech ballet slippers in favor of anachronistic pointe shoes that cost $50 a pair and can wear out after a single performance. Edward Tenner, a student of technology whose book *Why Things Bite Back* could give ammunition to Luddites who fail to read it carefully, points to another such case: the rise of the high-tech bowling ball. It seems that technology in this field is so advanced that a new generation of balls is sharply changing the nature of the game, making it much more "strike intensive," in Tenner's words. Purists are appalled, contending that the skill and strategy involved in nailing a difficult split are falling by the wayside.

What to do if you detect the symptoms of selective Luddism in your household? Relax. In the end, selective Luddism

makes a certain sense, for who can foretell the impact of a new technology? Who imagined, for instance, that air conditioning would transform Houston into one of the largest cities in North America? That the birth control pill would fuel the sexual revolution? That computers would facilitate adjustable-rate mortgages? Or that television would become the predominant cultural medium of our age? Only a clairvoyant. The rest of us, swept along on the tides of history, must take technologies as they come.

Besides, people have always adopted new ideas at different rates. After citrus was found to prevent scurvy, years went by before the Royal Navy adopted the measures that led the English to be called Limeys. Sometimes the problem is that it takes a while for people to figure out how a new technology might best be used. The full effect of electrical power on factory productivity, for example, took years to manifest itself.

And some new technologies—personal computers, for instance—were probably adopted too soon, rather than too late. Billions have been spent on computer technology, but there is serious debate over whether any productivity gains have resulted. It's doubtful, though, that computers would get as good as they are going to be without first being ornery and difficult to use.

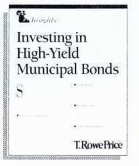
So maybe what I'm calling selective Luddism is really just people's natural need to grope their way into tomorrow. Very, very few of us, after all, wish to abandon technology altogether, much as we may lament the various technological developments that have changed our lives. I have noticed that admirers of primitive tribal cultures make no effort, when they get home, to have the telephone taken out, and I am pleased to note that even hardened reactionaries, like the narrator of John Lanchester's novel *The Debt to Pleasure,* usually make an exception for dentistry as an unalloyed good resulting from the modern age.

In a sense, we're all selective Luddites, and true enemies of technology stand out only because of the depth and arbitrariness of their convictions, which are closer to religion than to reason. Even the Unabomber didn't hate all technologies. Explosives, for instance, seemed to suit his Luddite mentality just fine. TR

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MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

MIXED MEDIA | BY STEVE DITLEA

Cloning Around

Glimpse the future of screen simulation

SIGGRAPH 98 ELECTRONIC THEATER
Video Review, Issue #125
www.siggraph.org
$60



MITCH BUTLER (LEFT); ROBERTO ZICHE

The wondrous weirdness of computer animation shows through in pieces like *The Smell of Horror* (left) and *Eroica*.

IT IS REGRETTABLE THAT aside from eye-catching effects in cartoons, movies and television ads, the general public doesn't get to witness the incredible progression of computer graphics. Mass-market movies such as *Antz* and *A Bug's Life*, for instance, represent just a small part of the technological and expressive innovation that the technology makes possible.

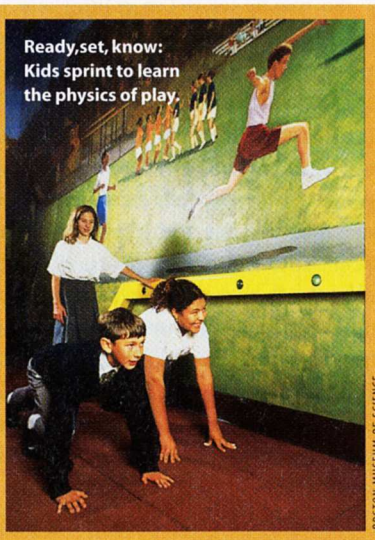
Every year, computer graphics professionals are treated to a show of cutting-edge work that we civilians seldom glimpse. The venue is an international conference called SIGGRAPH—the Association for Computing Machinery's special interest group for graphics. At the 1998 gathering in Orlando, the hottest ticket this side of Disney World was for the Electronic Theater. There were only seven showings of this program offering the best of computer graphics: scientific visualizations, technical breakthroughs, artistic statements, commercial appeals, student demos and yes, the latest in Hollywood special effects and animation.

The Electronic Theater was open only for the four days of SIGGRAPH. But not to worry. The conference organizers have made most of its three dozen pieces available on videocassette. To anyone who may have been put off by the sameness of commercially released computer graphics collections in the past, this collection presents the real deal—a taste of explosive originality. The range of expression astonishes: visionary, rational, profound, funny, quirky, awe-inspiring. My non-techie wife, who resisted the idea of watching a computer graphics collection, was mesmerized by the variety and creativity of the productions here.

More than half the pieces depict computer-mediated human gestures, physiognomies and stances, and they convey emotion as effectively as hand-drawn cartoons or live actors. From the goofy penguins sliding down snowy slopes on skis made of floppy fish in Stephen Rawlins' "The Hungry One" to the final seconds of the surreal "Bingo," a clown skit gone haywire based on a play staged by Chicago's Neo-Futurist Theater Company, it's clear

EXHIBIT

Laws of Childhood Motion



BOSTON MUSEUM OF SCIENCE

Ready, set, know: Kids sprint to learn the physics of play.

Ask a 6-year-old to recite Newton's laws of motion and the best you're likely to get is theorizing about fig-filled cookies. But let the same kid loose amid swings, slides and seesaws and she's bound to know what to do. Exhibit planners at Boston's Museum of Science were counting on that when they put together their newest permanent exhibit, "Science in the Park."

Science in the Park brings the playground indoors, pairing park toys with more traditional experimental setups that demonstrate the same physical principle. A seesaw, for example, sits next to a giant lever with a 225-kilogram weight hanging from one side of the fulcrum and climbing ropes hanging from the other—the notion of torque springs to life as kids see how much easier it is to lift the weight when they tug the rope farthest from the fulcrum. To demonstrate variation in surface friction, the museum has assembled an assortment of shoes; kids drag the shoes across different surfaces and read a built-in force meter to compare resistance.

By offering kids the chance to play with the equipment, the museum encourages them to be amateur scientists, experimenting with forces and motion to answer such questions as: What makes the fastest swing? Which shoes are best for running? The youngest children, says exhibit planner Susan Sunbury, can "feel the physics" as they run, jump, spin and swing. Slightly older kids can measure their movement or that of models using colorful distance markers and motion-sensor-triggered lights. If they're ready to "get a little quantitative," they can try to interpret the computer-generated graphs of force and velocity that are displayed at many of the activity sites.

The exhibit is part of a long-term strategy to transform the museum into an active center of "inquiry learning." Vice President of Exhibits Larry Bell says he hopes this "science thinking skills approach" will be a model for other museums nationwide. **—Rebecca Zacks**

computer graphics have made a great leap forward in their power to show the nuances of personality. Rather than just replicating faces and bodies, the pieces filter and augment human traits, whether the downhill postures in "The Hungry One" or the woodenness and plasticity of "Bingo." The result is special effects no live-action production could ever afford. Send in the clones!

Since the first SIGGRAPH conference 25 years ago, the quest for greater expressiveness through silicon has eked out incremental triumphs: from spindly wireframe graphics to form-defining texture mapping of surfaces. Computer graphics artists first captured the subtle ways that light is reflected from surfaces, later perfecting the visual melding of morphing. Along the way have come marvelous breakthroughs in realism, in effects such as the shimmering of water and the behavior of particles in smoke and fire. In the blink of an eye, it seems, computer graphics has arrived at the point of being able to portray body language and facial expressions convincingly.

Realism may be within reach, but virtual personality calls for stylization. Several of the outstanding pieces in this edition of the Electronic Theater incorporate ages-old human stylizations—masks. A Japanese entry, "Noh Mask" from Hitachi, shows in Zen-like elegance how a classic depiction of a face can display a wide range of expressions with slight changes in computer-generated lighting. A preview of an upcoming LucasArts computer game, "Grim Fandango," is a send-up of a 1940s-style coming attractions trailer for an adventure flick, featuring characters with faces like Mexico's grim Masks of the Dead. And speaking of noir-ish entertainment, we have "The Smell of Horror"—a chilling, cartoonish encounter in black and white in a strange house being tested for toxic fumes. Accentuating the disturbing weirdness of this piece are the oddball, mask-like grimaces of its two human protagonists.

Because of commercial rights considerations, the video compilation omits about a half-dozen clips that were shown at the Electronic Theater in Orlando. For this reason you won't see scenes from such big-budget highlights as *Titanic*, *Flubber* and *Antz*. Such footage is scarcely missed, though, thanks to the contribution from

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Promoting Innovation: The Dynamics of Technology and Organizations

January 25-28, 1999 July 12-15,1999

Harvey M. Sapolsky
James P. Womack
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Successful innovation links technical advances to organizational change. MIT faculty and research associates lead intensive case studies of innovation in the energy, telecommunications, defense, chemical and automotive sectors. Other topics include lean engineering, public-private interrelationships, restructuring markets and organizational strategies for change.

PROFESSIONAL PROGRAMS

smaller and less famous outfits. For example, though it's on a professional par with any of the big-budget clips, "The Smell of Horror" is just one step away from a garage video. Its creator is Mitch Butler, head of a Boise, Idaho, computer graphics house for corporate presentations who wanted to branch out into entertainment. With the Electronic Theater as his goal, Butler and a friend harnessed a network of Intel processors to produce this short work, which has since its SIGGRAPH debut garnered interest from Disney, Dreamworks and MTV.

There's more on this tape. Sega's thrill-ride simulation, "Wild River," overflows with stunningly realistic renderings of undulating, splashing, bubbling water. On the arty side, the French neo-Chagall "Cloison (Partitions)," with its curving, squirming cubicle dwellers, bursts with spirited originality.

Sure, it's easy to spot imperfections in some of these pieces, such as the misshapen hands in the knight-in-armor tour-de-force "Eroica," or the overly rigid body language of the girls turning somersaults on a sunny beach in a French entry, "Dolly à la Plage." But these artifacts pale in comparison with the medium's potential. One warning: Viewing this sampling of computer graphics at its creative best will make it much harder to be awed by the imagery that fills today's TV and movie screens. So enjoy at your peril. TR

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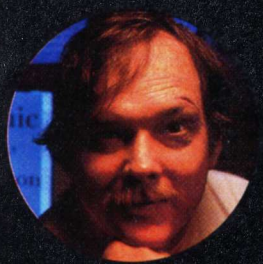
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—Herb Brody

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW
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ERIC RAYMOND
February 25, 1999

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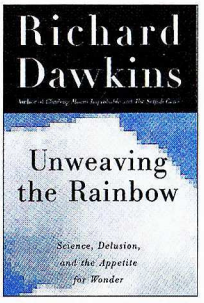
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PAGES | BY WADE ROUSH

Barcodes in the Stars

UNWEAVING THE RAINBOW: Science, Delusion, and the Appetite for Wonder
by Richard Dawkins
Houghton Mifflin, 336 pp., $26



RICHARD DAWKINS' 1989 book *The Selfish Gene* has persuaded many readers that we are, at bottom, vehicles for a genetic program. Our DNA exists to copy itself, but it does so by first building a conscious human organism. That's lucky for us; how many chunks of matter in the universe ever get to experience sunsets, or sonnets, or sex? Many people, however, take Dawkins to be saying that since our genes are in charge, any meaning we may happen to see in life is illusory.

Unweaving the Rainbow is Dawkins' eloquent reply to this depressing charge. Biologists may be unsentimental about their subject, he says, but that doesn't make them unfeeling. And there may be no grand design in life, but there is plenty to be awestruck about. "To accuse science of robbing life of the warmth that makes it worth living is so preposterously mistaken, so diametrically opposite to my own feelings and those of most working scientists, I am almost driven to the despair of which I am wrongly suspected," he writes.

Science can be the stuff of poetry, though it is the rare poet who has seen the possibilities, Dawkins argues. He proceeds to demonstrate himself what he calls "good poetic science"and "bad poetic science." In three delightful chapters, he talks of barcodes in the stars, in the air, and in the courtroom—meaning the Fraunhofer lines in the spectrum of a star's light that reveal its elemental makeup, the distinct patterns of harmonics in voices or the sounds of musical instruments, and the Southern blots scientists use to fingerprint a person's DNA. What excites Dawkins about the metaphor is the idea that nature's barcodes are full of meaning waiting to be deciphered.

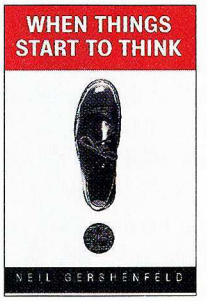
Bad poetic science, to Dawkins, includes astrology and the paranormal, whose prevalence in popular culture he attributes to an excess of childish credulity. Interestingly, he also singles out fellow science popularizer Stephen Jay Gould for allegedly misleading students of evolution with forced analogies and lazy generalizations (such as the use of the term "episodic" to embrace three very different kinds of evolutionary discontinuity: catastrophic mass extinctions, macromutations and punctuated equilibrium).

But there is far more revelry than rancor in this book. Dawkins' wide-eyed enthusiasm as he explains how selfish genes can still cooperate, how our DNA is a digital archive of the environments in which our ancestors survived, and how the human brain is the most sophisticated virtual reality machine ever built, is the antithesis of bleakness. With Carl Sagan gone, the English-speaking world needs a new poet laureate of science. Richard Dawkins now bids for the title.

The Digital Coffee Mug

WHEN THINGS START TO THINK
by Neil Gershenfeld
Henry Holt and Co., 221 pp., $25

AS TOOLS FOR EVERYDAY LIFE, TODAY'S PCs are hopelessly complex and clunky, Donald Norman argued in his recent book *The Invisible Computer (reviewed in* TR, *September/October 1998, p. 82)*. For those of us frequently exasperated by our own computers, Norman's book offered comforting validation. It also offered a tantalizing solution: Make computing ubiquitous, by replacing PCs with networks of small, dedicated "information appliances." Yet many of the appliances Norman proposed as examples, such as the "home financial center" that pays bills electronically and communicates with the checkbook appliance and the credit card appliance, sounded just as complicated as the computers they were intended to replace.



Physicist Neil Gershenfeld, co-director of the MIT Media Lab's Things That Think (TTT) consortium, rescues Norman's concept by making a crucial addition. If computers are going to be ubiquitous, he argues in *When Things Start to Think*, they had also better be unobtrusive. The researchers in Gershenfeld's consortium study ways to make computers truly invisible, by embedding them in traditional household objects—from coffee mugs to cardigans—that we all know how to use.

Many of these ordinary artifacts efficiently solve problems that still stump computer manufacturers, Gershenfeld points out. The translucent fibers in a sheet of paper, for example, spread light within the sheet before it leaks out in all directions. This creates a uniform illuminated background for printed text and makes words readable from any angle, feats unequaled by even the best laptop LCDs.

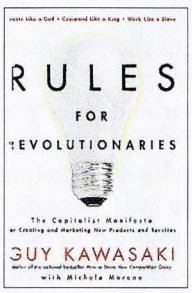
Since paper is such a versatile technological medium, computing power should be used to enhance rather than supplant it, Gershenfeld argues. A Media Lab innovation called reusable paper, for example, is covered with "smart toner" made from capsules containing magnetized white and black particles. The capsules can be switched on or off by a row of electrodes in a printer, and sheets can be rewritten again and again.

Gershenfeld's tour of the near future continues with wearable computers that augment your senses and electronic cash that implements your social values (a donation to a fund-raising group, for example, could be programmed to decrease in value if spent on administration). The philosophy embodied in such inventions is that machines should provide information whenever, wherever and in whatever form users want, should be responsive to their environments,

and should attend to their own needs. Better sensors and displays and new ways of hiding microelectronics in everyday materials can get us most of the way toward these goals, Gershenfeld's stimulating book suggests. "By bringing smarter technology closer to people," he predicts, "it can finally disappear."

Poop Like an Elephant

RULES FOR REVOLUTIONARIES: The Capitalist Manifesto for Creating and Marketing New Products and Services
by Guy Kawasaki, with Michele Moreno
HarperBusiness, 224 pp., $25



GUY KAWASAKI WAS PART OF the team that developed the Apple Macintosh in the early 1980s, and he has spent much of his time since then thinking and writing about the factors behind a new product's commercial success. The conclusion this irreverent, battle-scarred computer industry veteran has reached is that the product is only a part of the story.

Sure, products with the right qualities are more likely to catch on. Specifically, Kawasaki thinks the best products are deep, indulging, complete, elegant, and evocative (DICEE)—meaning that they grow with their users, do more than they strictly need to, come with service and support, reflect their creators' pride and engender creativity.

But creating and marketing such products takes people with the right attitudes and practices, Kawasaki argues. Some of his most important rules for revolutionaries are to ignore naysayers, to "evangelize" a product so that customers don't simply buy it but believe in it, and to "eat like a bird, poop like an elephant." This unappetizing (but memorable) dictum means companies should constantly gather information about their industry, customers and competitors, and should at the same time cultivate trust and goodwill by giving away as much of their own information as possible.

You know what they say about hindsight. Indeed, if Apple Computer had followed this advice by licensing the Macintosh operating system to other computer manufacturers in the 1980s, the company might never have lost so much ground to Microsoft. Kawasaki's shrewd, entertainingly presented rules will help aspiring entrepreneurs avoid such blunders.

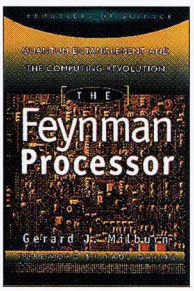
If reading a how-to book could prepare every Steve Jobs wannabe to succeed with a revolutionary new product, of course, there wouldn't be so much secondhand office furniture for sale in Silicon Valley. "Many revolutionary ideas are the result of blind, dumb luck," Kawasaki concedes. The Macintosh, for example, might not have survived at all if Aldus (now Adobe) hadn't developed PageMaker, the "killer app" that made the Mac indispensable for desktop publishing.

Even if Kawasaki's rules were futile, however, his book would still be valuable as a glimpse of the rash mindset found within many of the hottest technology startups. He reveals, for example, that Apple's Macintosh division was "arguably, the greatest collection of egomaniacs in Silicon Valley, and Silicon Valley is full of egomaniacs, so this is saying a lot." Only the unreasonable, Kawasaki seems to be saying, can start revolutions.

Spooky Computing

THE FEYNMAN PROCESSOR: Quantum Entanglement and the Computing Revolution
by Gerard J. Milburn
Perseus Books, 213 pp., $23

IF NOT FOR THE RECENT WAVE OF FEYNmania, Gerard Milburn's new book would probably have been called The Einstein Processor. In a 1935 paper, Einstein and colleagues Boris Podolsky and Nathan Rosen tried to discredit the new theory of quantum mechanics by demonstrating that it led to seemingly impossible results. The famous "EPR" paper showed that if two particles, A and B, are related by some past quantum interaction and an observer measures A's momentum, then B's momentum must instantaneously take on the opposite value—even if A and B are light-years apart. Einstein scorned this result, with its implication of faster-than-light communication, as "spooky action at a distance."



Far from undermining quantum mechanics, however, the EPR paper proved to be science's first glimpse of a bizarre phenomenon: quantum entanglement. Milburn, an Australian theoretical physicist working in the field of "quantum computing," is the first to make entanglement and its real-world significance penetrable for the lay reader.

For other physicists, Milburn writes, the EPR argument pointed to realities Einstein was reluctant to accept. Most systems in the familiar world have definite states: a tossed coin comes up either heads or tails. But in the quantum world, governed by the uncertainty principle, different states commingle until measured; a bit can be a blend of a 0 and a 1, called a "qubit." To represent this blending in calculations of the odds in quantum experiments, Milburn explains, Richard Feynman invented a quantity called "probability amplitude." Entangled particles that seem to communicate instantaneously are simply obeying Feynman's rule for adding probability amplitudes.

This esoteric realm has some remarkably practical implications. A computer using quantum versions of the classic logic gates such as AND, OR and NOT would be able to process all possible inputs simultaneously, Milburn explains, making it useful for problems such as finding the prime factors of very large numbers. (The magnitude of this task is the basis of today's best encryption methods.)

Researchers have devised simple quantum logic gates and used entanglement to instantaneously impress one particle's quantum state upon another faraway particle—opening up "teleportation" as a potential way to move information inside a computer. Though the work of Milburn and his colleagues revolves around uncertainty, they show little of this quality themselves when they predict that quantum entanglement will be the key to future gains in computing power. "It may take decades, perhaps a century," Milburn writes, "but a commercially viable quantum computer is a certainty." TR

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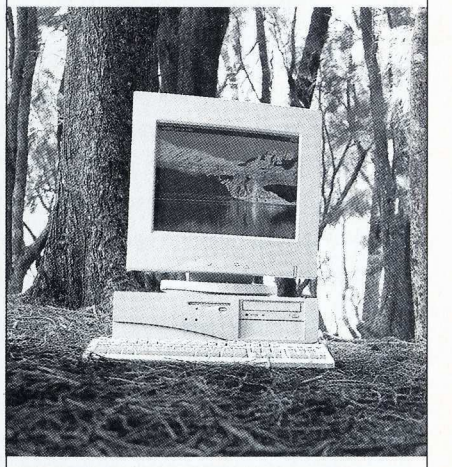
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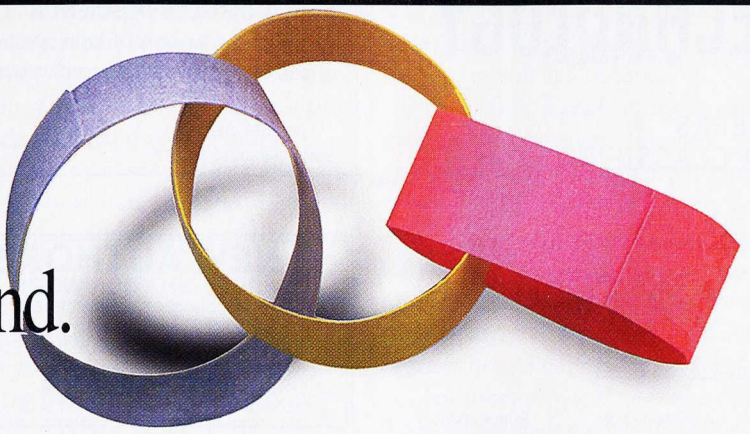
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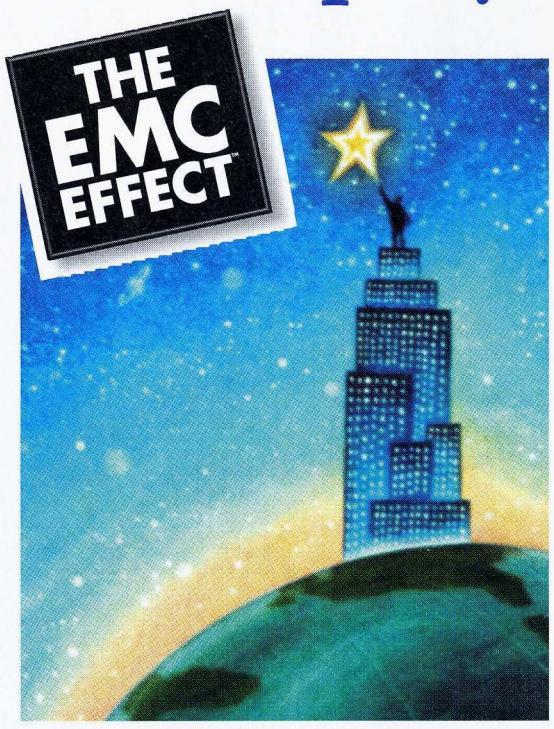
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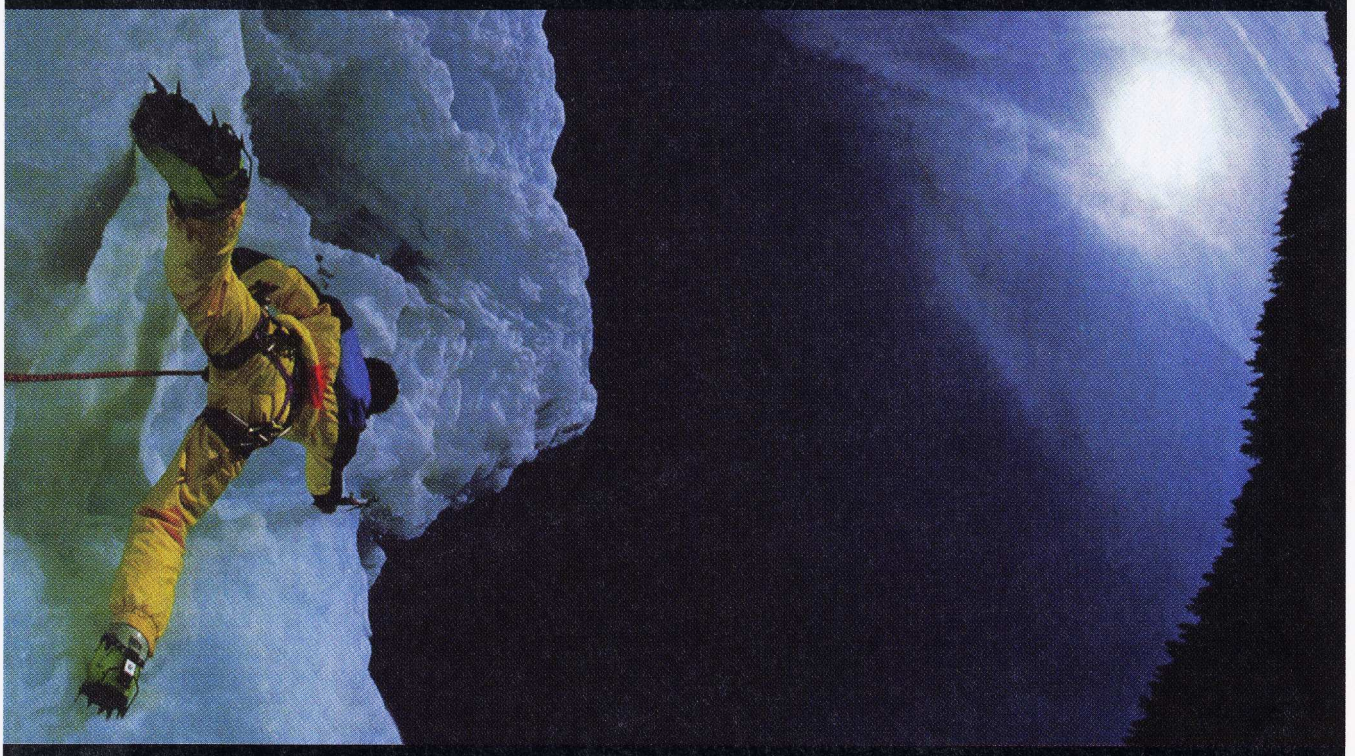
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Raytheon credits the discovery of microwave cooking to a grade-school-educated engineer named Percy L. Spencer. One day in 1945, Spencer was walking through a radar test room with a chocolate bar in his pocket; he came too close to a running magnetron tube and the candy began to melt.

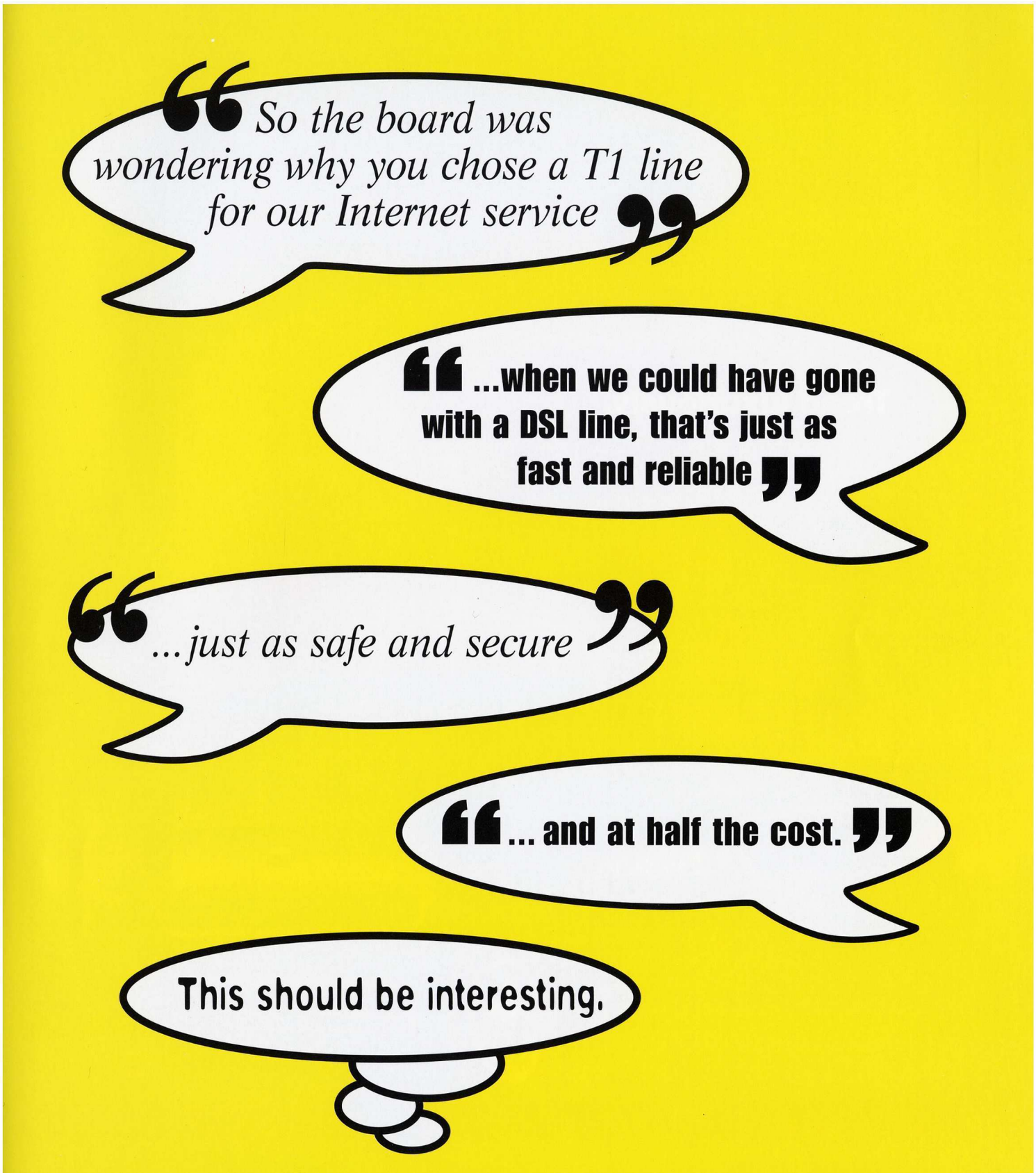
Spencer was already known at the company for his curiosity and ingenuity, and he reacted true to form—he pointed the magnetron at kernels of corn and watched them pop, aimed for an egg and saw it cook so quickly it exploded. Soon, Raytheon officers were sampling microwaved meals in the executive dining room and within a few years the company was marketing the Radarange for $2,000 to $3,000.

At that price, the Radarange was primarily a commercial cooker, providing warm meals on trains and ocean liners, and in restaurants and hotel dining rooms; some establishments offered special all-microwaved meals to promote the new technology. Early efforts to sell home machines through a licensing agreement with the Tappan Stove Co. were unsuccessful. But in 1963, a chance dinner meeting between two Raytheon executives and the president of Amana Refrigeration, Inc., all visiting Chicago, resulted in the sale of Amana to Raytheon. Raytheon capitalized on Amana's experience in marketing and distributing consumer goods, and in 1967 introduced the under-$500 countertop Amana Home Radarange.

Today, 90 percent of American homes have microwave ovens. And though Spencer never profited from his patent on the device, his early snack experiments were prophetic; many of us use our microwaves most often to pop popcorn and, some pastry chefs argue, a few seconds in the microwave is simply the best way to melt chocolate.

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If yours is selected, you will win a year's subscription to *TR*. This month's story was suggested by Bob Anslow, MIT '54, who worked at Raytheon from 1956 to 1965 and shared in that fortuitous Chicago dinner. Send a few paragraphs to: Trailing Edge, *Technology Review*, MIT Building W59-200, Cambridge, MA 02139; or e-mail: trailingedge@techreview.com.



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